System Level Economic Analysis of Swine Diet Modifications

BY

YI-HUNG LIN

Bachelor of Business Administration
National Taipei University
Taipei, Taiwan
1993

Master of International Economics
National Chung Cheng University
Chiayi, Taiwan
1998

Master of Art in Economics
Duke University
Durham, NC
2001

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
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Dissertation Approved:

Dr. Arthur Stoecker
Major Advisor

Dr. Francis Epplin

Dr. Raymond Schatzer

Dr. Scott Carter

A. Gordon Emslie
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Swine production has grown dramatically in recent years in Oklahoma. In 2002, hog and pig production was the state's third largest agricultural industry in term of cash receipts, which were estimated to be $378 million dollars (Oklahoma Department of Agriculture, Food, and Forestry). These large swine feeding operations generate huge quantities of manure each year. Manure could be a valuable by-product to swine feeding operations in term of nutrients and organic matter if its nutrients can be recycled through appropriate land application. Swine manure is a major source of plant nutrients, such as nitrogen, phosphorous and potassium, and can be used as a substitute for chemical fertilizers in the production of row crops and pasture grasses. There are several positive benefits associated with manure application (Theil, 2002). Nutrients are recycled from manure back to the soil for plant growth. Manure replaces chemical fertilizers and adds organic matter to improve soil tilth, increase water holding capacity, reduce wind and water erosion and improve soil aeration (Fact Sheet-2250, Oklahoma Cooperative Extension Service).

Manure and Soil Fertility

The soil organic matter (SOM) content is significant criteria for determining soil quality. Soil organic matter is composed of the tissues and cells of soil organisms, as well as plant and animal materials in various stages of decomposition (Zhang, 1998;). The organic matter in soils serves as an energy source for soil microorganisms, which in turn promote plant growth (Whalen, 2002; Theil, 2002). SOM builds soil structure and improves soil tilth. It also reduces crusting and runoff by regulating the flow of water, and increasing the infiltration of water (Fact Sheet-1734, Oklahoma Cooperative Extension Service). High quality soils generally contain high SOM, while low quality soils are with low SOM contents. In Oklahoma, most soils contain less than 1percent of soil organic matter, which is considered low (Zhang et al., 1998). As demonstrated by Magruder Plots in Stillwater OK, continued application of manure can supply plant nutrients and organic materials. Swine manure, generally with more than 20 percent of solid and slurry (Fact Sheet-1734, Oklahoma Cooperative Extension Service), contains large amount of organic matter (Zhang et al., 1998). Applying swine manure can slow down the depletion of SOM due to microbial decomposition and erosion by supplementing organic materials to soils.

In addition to its functions as a plant nutrient source or soil amendment, swine manure can also be used to neutralize soil acidity and raise soil pH values (Zhang, 1998). Long-term experiments and field studies have demonstrated that applying manure to acid and neutral soils not only supplies organic matter and needed nutrients for plant growth but also reduces soil acidity. In a study conducted in Eastern Oklahoma, swine and poultry manure were applied on the surface for 5 years. The pH values of the top 2 feet of soils receiving manure were significantly higher than the pH of the soils that received no manure during the same period (Zhang, 1998). Animal manure has been applied for many decades on part of the Magruder plots at OSU Agronomy Research Farm in Stillwater OK. The pH value of the top six inches of the soil in the plots where manure was applied was 6.32. This was greater than the pH where no fertility was applied (Check plot) or the pH values where chemical fertilizer (P, NP, NPK, or NPKL) was applied. As a result, plots that received treatments other than manure needed lime to correct the low pH to maintain optimal crop production. In Oklahoma, where many fields are acidic, swine manure, which can maintain soil the pH in the ideal range for most field crops may be a good amendment. The liming effect of manure, which can raise soil pH due to the lime like materials such as calcium and magnesium in it can also improve phosphorus availability and reduce aluminum toxicity (Zhang, 1998).

Swine manure can be an economical source of plant nutrients and a valuable soil amendment to improve soil quality and maintain soil pH. However, an appropriate and environmentally sound manure management requires that the application rates of manure should be based on crop nutrient requirements. It may be a great challenge for intensive and specialized hog production operations with limited applicable cropland. In Oklahoma, swine production has experienced rapid growth over the last decade. The total number of pigs in Oklahoma during 2002 was 2,240,000 head, a dramatic increase from the 215,000 head in 1990 (Oklahoma Agricultural Statistics Service). However, the industry’s structure had also changed rapidly and substantially over the same period. In the 1990s, the hog industry in Oklahoma began building large feeding operations in rural areas. The number of farms with an inventory of at least 5,000 pigs increased from 10 to

40 from 1993 to 2002. On the other hand, the number of farms with the inventory of less than 500 pigs decreased from 3,430 to 2,410 over the same period. The 40 largest farms produced 89 percent of all the pigs marketed in Oklahoma during 2002 in comparison with only 40 percent during 1993. In contrast, the market share of production from small farms (less than 500 head per year) dropped from 35 percent in 1993 to 2 percent in 2002. Large pig production operations appear to realize significant economies of size. However, large, intensive pig production operations have been associated with environmental problems and have aroused public concern about waste disposal. Management of manure in an environmentally sustainable manner is one of the critical issues facing the hog industry in Oklahoma.

Potential Runoff and Water Pollution

Most manure management systems in Oklahoma are lagoon systems. The general structure of lagoon based swine waste management systems may be divided in three broad categories: in-house waste management, waste storage/treatment, and waste application or disposal. Studies conducted by Carreira and Stoecker (2000) found that land available for waste application is a crucial factor in determining total waste management costs. With concentrated animal production, the huge amount of manure can result in either increases in cost of hauling manure away from the farm, or excess land application that threatens the safety of both surface and ground water.

Over application of animal manure can result in undesirable nutrient and mineral accumulation in soils. Movement of nitrogen and phosphorus in excess amounts from wastewater and manure to water and air can cause significant environmental problems.

Excess phosphorus and nitrogen that enter surface waters through runoff will upset the balance in aqueous ecosystems, and cause the eutrophication phenomenon (Fact Sheet-2249, Oklahoma Cooperative Extension Service). Eutrophication is the process of organic enrichment of water bodies, which promotes the growth of undesirable algae and aquatic weeds at the expense of others (Shuman, 2004). Nutrient abundant runoff due to over-application of manure has been associated with accelerated eutrophication of lakes and streams, and algal blooms. The growth of certain harmful species because of eutrophication, and the oxygen shortages caused by their death and decomposition may restrict water use for fisheries, recreation, and industry (Fact Sheet-2249, Oklahoma Cooperative Extension Service). Furthermore, the algal blooms accompanied with the eutrophic effect not only produce toxins harmful to fish, but also deplete the water of oxygen. Many drinking water supplies throughout the world experience periodic massive surface blooms of algae, which contribute to summer fish kills, unpalatability of drinking water, and formation of carcinogens during water chlorination (Kotak et al, 1993; Palmstrom et al., 1988; Sharpley et al., 2001). These nutrient losses to the environment can also occur from the production site or during storage. As land available for waste application is limited, leaks and spills from over-loaded manure lagoons have also caused many problems associated with pollution, health, and safety (Becker, 2002).

Most crops require about eight times as much nitrogen as phosphorus. However, the N: P ratio of lagoon effluent is close to 4:1 (Fact Sheet-2249, Oklahoma Cooperative Extension Service). If manure was applied at rates designed to supply crop nitrogen requirements, the amount of phosphorus in applied manure would be considerably greater than the amount removed in harvested crops. That is, land applications based on crop nitrogen requirements result in phosphorus buildup in the soils (Fact Sheet-2249, Oklahoma Cooperative Extension Service). Phosphorus buildup due to the applications of phosphorus in excess of crop uptake requirements in turn has a negative impact on surface water quality (*Resource*, 2002). Phosphorus is transported to a water body either by being dissolved in surface runoff or by being attached to eroded soil particles (Fact Sheet-2249, Oklahoma Cooperative Extension Service). Increasing the amount of phosphorus in soils increases the amount of dissolved P in water that passes over or through soils. This will result in increased levels of phosphorus in soil solutions. When soil erosion occurs, the phosphorus attached to soil particles is carried with the water to the stream or lake. However, some studies found that phosphorus in runoff from a pasture is primarily in the soluble form and not in a compound with soil particles form (Shuman, 2004). In the research of Fleming *et al*. (2001), it was found that as much as 98 percent of total phosphorus applied on pastures was lost in overland flow.

Furthermore, nitrogen is usually not a primary agent for freshwater eutrophication. It is usually phosphorus that is the limiting nutrient controlling freshwater eutrophication and algal blooms (Sharpley et al, 2001). Excessive levels of P in water often promote the growth of undesirable algae and aquatic weeds, and shortage of oxygen (Shuman, 2004). Lake water P concentrations at around 0.05 ppm are considered critical; at values above this, eutrophication is accelerated (Fact Sheet-2249, Oklahoma Cooperative Extension Service). These problems of low quality water often limit water use for fisheries, recreation, industry, and drinking.

Environmental Regulation and Legislation

The concerns associated with environmental pollution by phosphorus runoff from agricultural production activities promoted the USEPA to propose a new National Pollutant Discharge Elimination System (NPDES) permit program (Huang et al., 2003). Under the new regulations of NPDES program, concentrated animal feeding facilities (CAFOs) must follow phosphorus-based nutrient management plans for land application (Huang et al., 2003). CAFO operators must estimate the phosphorus requirements of crops based on realistic crop yields, analyze sample soil to determine soil test P, and then restrict application to quantities that do not exceed the net amount of phosphorus needed. The operators must also restrict nitrogen application not to exceed the nitrogen needs of crops, when soil test P is low (Huang et al., 2003).

In Oklahoma, sixty-three percent of the assessed river miles have low water quality that do not support or only partially support aquatic life uses. Forty-three percent of the assessed lake acres do not support or only partially support aquatic life uses (National Water Quality Inventory: 1998 Report to Congress). While pollution from factories and sewage treatment plants has been dramatically reduced, agricultural activities are named by the Oklahoma Department of Environmental Quality, Water Quality Division as the leading source of pollution in the state's rivers, lakes, and ground water. Although CAFOs result in concentration of large quantities of manure and wastewater in small areas (USEPA, 2004), they can be easily identified, and are defined as the point sources of P pollution by the Clean Water Act (CWA). The discharge of pollutants from those CAFOs to waters of the United States is currently under strict regulation by the National Pollutant Discharge Elimination System (NPDES) permit program. Therefore, it is expected that improvement in the control of point source discharges of P will be made, and will help reduce the environmental burden imposed by the CAFOs. The relative contributions of P from small animal feeding operations (AFOs) to U.S. water bodies, on the other hand, have been primarily ignored (Carpenter et al., 1998; Sharpley et al., 2001). Small animal feeding operations are regarded as the non-point rather than point sources of P, because it is difficult to identify and control them. The vast majority of farms with animals in the U.S. are small. USDA data indicates that about 85 percent of these farms have fewer than 250 animal units (USEPA, 2004). There are approximately 450,000 AFOs in the United States (USEPA, 2004). To protect fresh water bodies from eutrophication, EPA in December 2000 proposed to redefine hog CAFOs. The new definition of a CAFO would lower the minimum number of hogs with body weight 55 pounds or more from 2,500 head to 750 head. Since CAFOs are regulated as point sources of pollution, any hog farm designated as a CAFO must have an NPDES permit or be exempted because of no discharge (Huang et al., 2003).

In February 1998, President Clinton released the Clean Water Action Plan to better address the environmental concerns with animal feeding operations. The CWAP identified polluted runoff as the most important remaining source of water pollution, and called for a coordinated effort by the U.S. Department of Environmental Protection Agency (USEPA), and U.S. Department of Agriculture (USDA) to develop a Unified National Strategy to minimize the negative impacts of AFOs on water quality and public health (USEPA, 2004). As part of this national strategy, a national performance expectation that all AFOs should develop and implement technically sound, economically feasible, and site-specific Comprehensive Nutrient Management Plans (CNMP) to reduce the polluted runoff from animal production was issued by the USDA and USEPA in 1999 (USEPA, 2004). The CNMP, which aims at preserving the livestock industry, and protecting soil and water resources generally consists of 6 components as follows (Zhang, 2003).

1. Manure and Wastewater Handling and Storage: Swine manure management consists of four stages, floor types of the animal house, collection methods, storage methods, and application methods. In each stage several possible methods can be used. The least cost equipment combination of methods of each stage is determined by location, size of operation, and nutrient constraint (Stoecker *et al*., 2000). Another issue relating to manure management at the facility is liquid /solid separation. Stoecker *et al.* (2001) outlined the cost structure of liquid /solid separation and compared it to the cost structure of other swine waste management systems. As season and type of production phase affect the nutrient content of the swine lagoons in Kansas, DeRouchey (2002) found that producers benefited from obtaining individual analyses from their lagoons when developing nutrient management plans rather than utilizing published reference values.

2. Land Treatment Practices: The treatment and practices applied on the land that receives manure also play an important role in determining the environmentally sound manure management plan. Wang (2002) found that conservation tillage practices reduce soil erosion, which in turn reduces particulate N and P losses.

3. Nutrient Management Plan: Phosphorus concentration in the runoff was directly related to the phosphorus application rate, with initial concentrations being higher than in subsequent runoff events. The concentration of phosphorus was highest in

the first runoff event after fertilizer application and found to decrease logarithmically or exponentially (Shuman, 2004). Percent loss of P to water resources depends on rates, soil P testing, and volume of runoff water (Shuman, 2004). Nutrient utilization standards that are protective of the environment would require that animal manure applications do not result in soil test phosphorus levels that exceed 120. Accurate assessment of available P content in manured soils is essential in manure management (Atia, 2002). The application method of manure is another important part of the nutrient management plan (Zhang, 2003). Stoecker *et al*. (2001) show how to use a computer algorithm to search a technically feasible combination of irrigation pipe, motor, and system output to minimize total manure treatment and application costs.

4. Record Keeping: How and what records the producer maintains may affect the waste management cost.

5. Feed Management Considerations: As non-ruminants, pigs lack the phytase enzyme to digest the P in grains, which is usually in the form of phytic acid. Swine diets are usually supplemented with inorganic P, such as dicalcium phosphate to provide sufficient levels of P for the animals. This increases total P content in manure, and in turn increases the P concentrations in runoff (DeLaune, 2002). Phytase can be used to convert unavailable phytic acid to relatively bio-available dietary P (Lei et al., 1992; Jongbloed et al., 1992, Cromwell et al., 1993, 1995). Phytase addition to swine diets thus dramatically reduces total P concentration in manure. However, some studies have found that the soluble P concentrations in the runoff are higher from the animals fed a phytase diet (More et al., 1998; Smith et al., 2001). The feed ration management may be coordinated with other manure management methods to reduce the total and soluble P content in

manure. For example, the aluminum chloride decreases the total soluble P content of the manure. Soluble P in runoff was reduced by 41percent by adding aluminum chloride to manure from swine fed a phytase diet (Smith et al., 2001). The manure application rate was restricted by the nitrogen needs of crops for the areas where P in soils is low (NRCS, 2000). Carter *et al*. (1996) show that total nitrogen excretion was reduced by 33 percent to 49 percent by lowering crude protein and adding crystalline amino acids.

6. Other Waste Utilization Options: When there is not sufficient cropland for manure application, finding alternative uses for manure is one option for AFOs. For example, the complete mix digesters can biologically stabilize manure, control odors and obtain methane recovery for electricity production (Moser, 2002). Mclntosh et al. (2000) estimated the profit and cost associated with alternatively using poultry litter as a livestock feed. Other utilization options may provide more profitable opportunities for animal waste, and help reduce the waste management cost.

Analysis framework for the Study

To comply with the NPDES permit regulation, hog CAFOs producing more manure derived nutrients than crop nutrient needs in the regions should use practically feasible methods listed in the CNMPs to manage manure and wastewater in environmentally sound manner. This study limits its analysis to option (1), (3), and (5) of the nutrient management plans. The options of land treatment practices and other waste utilization as well as the efficiency of record keeping are not included for analysis in the study. The only alternative use of pig manure is assumed to be off-site disposal. Hog feeding operators could pay for having their excess manure hauled away from their operations, if they had inadequate cropland to comply with manure application restriction. The type of operation and the size of hog production are assumed to be feeder pig to finishing operations with 2000, 4000, and 8000 pigs at any time.

Feed ration management is an important component in the CNMPs in term of its direct effects on hog production and other components of manure management. In fact, both the nutrient content of manure and the rate of gain are highly related with the nutrient content in diets. Traditionally, pig feeding operators and nutritionists managed to maximize performance. However, research on pig growth response to nutrients had showed that diminishing returns to additional nutrient occur as the maximum response is approached (Fuller et al., 1993; Gahl et al. 1995). As the rates of gain in response to equal increments of nutrients decrease near maximum gain, the production of the most economic gain is determined by the relative price of pork and feed, and generally will not coincide with that for maximum growth. Even without considering the waste management cost associated with the amount of nitrogen and phosphorous excreted, swine diets formulated using diminishing returns concepts would have resulted in greater profits than diets formulated for maximum gain (Heady *et al.* 1954; Gahl *et al.* 1995). The literature is not short of research on swine profit maximization problems. Using a deterministic swine model, Boland *et al.* (1999) analyzed the optimal feeding program for a continuous operation with instantaneous replacement with identical, but younger animals. They found that phase feeding that varies nutrient density over time to avoid feeding excess nutrients to animals is recommended for the pork producer's profit maximization problem. In the growth model of Fawcett and Whittemore (1976), the utilization of digestible energy and protein components of the feed intake were partitioned into live body gain, urinary loss and heat loss. They proposed that growth response to nutrient intake could be best characterized by daily weight gain and the composition of that gain. In their pig growth model, isoquants and isocomposition functions were mapped into a diet space with the axes of daily digestible energy intake and daily digestible protein intake (Fawcett *et al*., 1978). This provides a basis to manipulate the growth rate and body composition of pigs of particular genetic potential by nutritional means. In their ration formulation model, Fawcett *et al.* (1978) further interpreted the chemical value of proteins and the ratio of the total protein retention to new protein synthesis as the factors determining the biological efficiencies of feed conversion. According to Fawcett *et al.* the chemical value is the minimum value obtained when the concentration of each essential amino acid in the feed is divided by the corresponding value in the preferred profile. Diets were formulated using linear programming (L.P.) in their study to achieve a particular daily weight gain, and a particular composition of that gain at least cost. Based on the works of Fawcett *et al*., Glen (1983) argued that the overall efficiency of pig production can be achieved by manipulating both the body weight gain and carcass composition of pigs at the whole animal level over feeding periods. Since feed input is the major factor in determining cost, growth, and profit, animal production is suitable to the application of dynamic programming for decision analysis. In his study, Glen (1983) developed a dynamic programming (D.P.) model to determine the sequence of least cost rations required to produce pigs of specified body weight and carcass composition at minimum cost. In the research of Kennedy *et al*. (1976), the dynamic programming model was also applied to analyze the decision problem for broiler production. The input-output relationships (biological functions) used in his study were from experiments conducted at the University of New England. Both the optimal composition of the diets and the optimal length of the feeding period were investigated in the model of Kennedy *et al*.

Diets recommended for maximum growth were formulated to provide more nutrients than those for maximum economic returns, which generally result in smaller sizes of animals and shorter feeding period. The over-supplementation of diets with nutrients to ensure maximum performance also generates excess amounts of excreted nutrients in feces and urine. Problems associated with inappropriate diet formulation, which provides more nutrients than necessary were exacerbated by the increasing number of large and intensive pig feeding operations. With limited cropland available for application of manure, the large quantities of nutrient laden manure increase the waste management costs, and reduce the net returns of hog production.

The objective of this study, therefore, is minimizing waste management cost by diet manipulation, while achieving production goals. Figure 1 illustrates the inter-relationship between feed ration, hog production, environmental protection policies, and other steps of manure management. It is a systematic diagram for hog feeding operations. The boxes represent actions that take place in hog feeding operations or by environmental protection agents. The arrows represent interactions between components. The arrows are double headed, which means interaction can occur in both directions. Feed rations through their effects on the amount of nitrogen and phosphorous excreted affect the choice of practical methods for the steps of manure handling and storage, and application in the comprehensive nutrient management plan. Consideration of increased manure storage and application cost due to more restricted regulations may have feedback effects on diet formulation. Diet formulation is also an important component in hog production. The nutrient content in diets affects the growth rate, and thus is a crucial factor in determining the optimal feeding period and the animal's final body weight. Marketing and environmental protection policies are considered to be the two main external factors that affect the CNMPs. Hog CAFOs develop and implement their optimal CNMPs to maximize their profit in accordance with the marketing opportunity and the environmental protection policies.

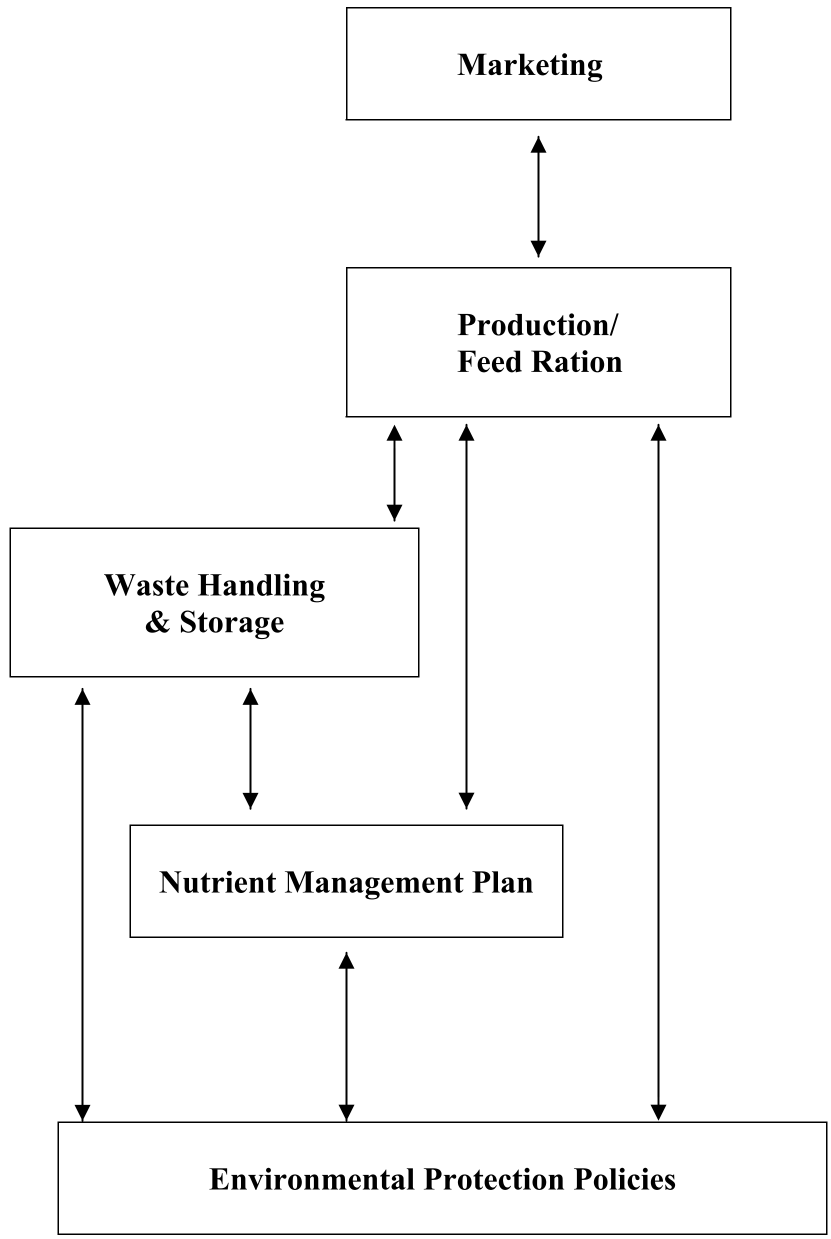

Figure I-1. Profit Maximizing Feed Ration & Its Relationship with Environmental Protection Policies, and Other Components in the CNMP.

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CHAPTER II

REVIEW OF THE NRC SIMULATION MODEL FOR SWINE GROWTH

In this study, pig growth was simulated on a daily basis by using the biological functions included in the *Swine Nutrition Guides*, National Research Council (NRC, 1998). Because the pig body can be reduced to protein and fat regardless of the tissues in which they are accumulated, these two fundamental components were chosen to represent body composition. In fact, the pig growth in the simulated model was mainly described by the biological functions of these two chemical body components. The nutrient requirements for each specific pig growth level were then estimated. The National Research Council (NRC) adopted the fractional method to estimate energy and protein requirements in pigs. It was assumed that dietary energy was employed first for maintenance, then for protein growth, and finally for fat deposition. Some scientists doubt that energy can be partitioned in such strict order (Fawcett *et al*., 1973). Fawcett *et al*. proposed that energy from feed intake after digestion forms a common pool from which all requirements are supplied at different rates according to the size of the pool and the stage of animal development (Fawcett, 1973). Nevertheless, the NRC concept (NRC, 1998) can also be interpreted as the efficiency of meeting various requirements by the pool-distribution hypotheses. Since the NRC growth simulation model was able to predict body weight gain and body composition during the growth period, this simulation model of pig growth and the accompanying nutrient requirements could be used to construct a profit maximization problem.

The NRC Growth Model

The NRC model assumed pig performance level was jointly determined by genetic, nutritional, health, and environmental factors. In the model, parameters for genotype, temperature and nutritional effects were used to determine the amount of protein accretion that was generated by available digestible energy (DE) in diets. For the amount of digestible energy intake (Mcal per day) above the 55 percent of the DE needed for maintenance is available for gain.

Whole Body Protein Gain

The daily whole body protein gain (grams per day); WBPG_t can be calculated by the following equation, which is a modification of the equation of Black *et al*. (1986):

$$\begin{aligned} \mathrm{WBPG}_t\ (\mathrm{g}) = {} & (17.5 \times e^{-0.0192\mathrm{BW}_t} + 16.25) \times (\mathrm{MPAR}/125) \times \\ & (1 + 0.015 \times (20 - \mathrm{T})) \times \\ & (\text{DE intake} - 0.55 \times \text{DE requirement for maintenance}), \end{aligned} \tag{2-1}$$

where

WBPG_t is the daily protein accretion rate for a particular day in grams per Mcal of DE above the 55 percent of DE required for maintenance.

BW is body weight in kg.

MPAR is the mean whole body protein accretion rate for a growing-finishing period in grams per day.

T is the effective ambient temperature in ^0C.

The deductive nature of the body protein generating equation presented above makes it more flexible and effective in predicting animal growth. However, it may be necessary to adjust the parameters of the body protein generating equation if empirical research shows significantly different results. The range of situations it can be applied to must be limited to the experimental conditions under which the empirical research was conducted. The pigs' body weight in the data set of those experiments that were analyzed ranged from 20 to 50 kg while the NRC model predicts growth from 20 to 120 kg. Applicability and accuracy decreases, when the equation is used to extrapolate results beyond this body weight range.

The mean fat-free carcass lean accretion rate (MFFL) over the range of 20kg to finished body weight can be empirically estimated using initial and final carcass fat-free lean. The mean fat free carcass lean accretion rate estimated can then be converted to the mean whole-body protein accretion rate by a factor of 2.55. That is,

$$\text{MPAR} = \text{MFFL}/2.55\,. \qquad (2\text{-}2)$$

Digestible Energy Intake

Based on literature, the NRC recommended that the daily DE requirement for maintenance is

$$\text{DE for maintenance (kcal/day)} = 110 \times \text{BW}_t^{0.75}\,. \qquad (2\text{-}3)$$

Given the mean whole body protein accretion rate in equation (2-2), equation (2-1) describes pig protein growth rate versus energy intake at each body weight. The protein growth rate varies in response to changes in body weight as the pig grows as well as changes in external situations. As the pig increases in body weight, the slope of the relationship of the protein accretion to energy intake gradually flattens. The second term of equation (2-1) is an adjustment of the slope for differences in generic type of protein accretion, causing the slope to be steeper for pigs with a greater potential lean growth rate. Energy intake was assumed to be limiting in this study. Further increments in energy intake beyond the maintenance requirements will increase protein and fat accretion. To avoid excess fat deposition, the amount of energy must be supplied too not greatly exceed the amount required for maintenance and protein growth.

For growing-finishing pigs allowed ad libitum access to feed, the energy content of the diets and energy requirement are assumed to determine pig feed intake. Pigs typically would not eat after their energy requirements are satisfied. The maximum energy intake of pigs was assumed to be entirely dependent on their body weight. An equation describing the relationship between maximum DE intake (MxDEI) and body weight for a combination of barrows and gilts was estimated by NRC as follows.

Maximum DE intake (MxDEI, kcal/day)

$$= 1250 + 188 \times \mathrm{BW} - 1.4 \times \mathrm{BW}^2 + 0.0044 \times \mathrm{BW}^3. \qquad (2\text{-}4)$$

In the case of restricted feeding, the pig's daily DE intake was controlled by a pig grower by providing a diet that must be greater than the daily DE requirement for maintenance (DEM), and less than the maximum DE intake.

Protein Requirements

Although energy and protein requirements are separately accounted for in the model, they interactively determine pig's growth. Energy works as a driving force in the pig production processes. To ensure a normal growth level, other nutrients, such as amino acid and minerals, must also be adequate. The lysine required for whole-body protein accretion each day (LysineG) was estimated using data from a wider range of experiments as follows:

$$\text{lysine for gain (LysineG, g/day)} = 0.12 \times \text{WBPG}_t, \tag{2-5}$$

where lysine for gain in grams is the amount of true ileal digestible lysine needed for daily whole body protein synthesis.

With prolonged DE intake at near or below that required for maintenance, it is unlikely that the low DE will be used indefinitely to generate body protein and lose body fat. As the energy intake falls from 1.5 to 1.0 times maintenance or below, the DE intake consistent with zero protein accretion is assumed to increase linearly from 0.55 to 1.0 times maintenance. In the profit maximization model, the maximum profit growth rate may be 95 to 98 percent of the potential growth rate (NRC, 1998). It is assumed that growing-to-finished pigs are not fed under severe energy and nutrient restrictions in the profit maximization model. No adjustment on the energy partition between maintenance and protein synthesis was made for the low DE diets in this study.

Similarly the whole-body protein growth rate, WBPG_t, can be converted to carcass fat free lean gain rate (grams per day), CFFLG_t, by the following formula provided by the NRC:

$$\text{CFFLG}_t(g) = 2.55 \times \text{WBPG}_t. \quad (2\text{-}6)$$

The carcass fat free lean weight in grams at the marketing day then was the sum of the initial carcass fat-free lean weight of feeder pig and the accumulation of daily carcass fat free lean gain over the growing-finishing period:

$$\text{FFL (g)} = \text{IFFL} + \sum_{1}^{T} \text{CFFLG}_t\ , \quad (2\text{-}7)$$

where IFFL is the initial carcass fat-free lean weight of feeder pig (gram), which can be estimated by the following formula:

$$\text{IFFL (g)} = 453.59 \times 0.95 \times \left[-3.65 + (0.418 \times \text{live weight, lb})\right]. \quad (2\text{-}8)$$

Metabolizable Energy and Fat Accretion

In the NRC model, fat accretion is a function of the energy surplus consumed by the animals and is not limited by other nutrients. Dietary energy and amino acids were allocated first to meet the maintenance requirements, then to protein growth, and finally to fat deposition in pigs. That is, dietary energy available for fat deposition is the digestible energy consumed minus that required for maintenance, and protein growth. Fat synthesized, FS_t, increases as the energy surplus given to the animals increases. The metabolizable energy (ME) is a proportion of the digestible energy intake.

$$\text{ME (kcal/day)} = 0.96 \times \text{DE intake} \quad (2\text{-}9)$$

ME available for fat synthesis can be obtained by subtracting ME required for protein synthesis and maintenance from ME intake.

The metabolizable energy (kcal/day) required for protein synthesis is equal to $10.6 \times \mathrm{WBPG}_t$.

The metabolizable energy required for maintenance represents the minimum energy requirement at each body weight.

$$\text{ME for maintenance (kcal/day)}$$

$$= 106 \times \mathrm{BW}^{0.75}. \tag{2-10}$$

Therefore, the metabolizable energy available each day for fat synthesis is the amount of ME intake minus that required for protein synthesis and maintenance; that is,

$$0.96 \times \mathrm{DE} - 10.6 \times \mathrm{WBPG}_t - 106 \times \mathrm{BW}^{0.75}. \tag{2-11}$$

The NRC assumes that one gram of fat can be synthesized with 12.5 kcal of metabolizable energy. The daily fat synthesized in grams was obtained by dividing the metabolizable energy available for fat synthesis by 12.5.

$$\mathrm{FSY}_t = (0.96 \times \mathrm{DE} - 10.6 \times \mathrm{WBPG}_t - 106 \times \mathrm{BW}^{0.75}) / 12.5. \tag{2-12}$$

Since fat tissue is 90 percent fat, the fat tissue gain in grams per day was obtained by transforming synthesized fat with a coefficient of 0.9.

$$\mathrm{FTG}_t(\mathrm{g}) = \mathrm{FSY}_t / 0.9. \tag{2-13}$$

The nature of the NRC model for protein and fat accretion implies that large increases in intake will lead to an increase in the growth rate, which will predominantly be fat. On the marketing day, the total carcass fat weight in grams, F, is the sum of the initial carcass fat weight of feeder pig and the accumulation of daily fat gain over the growing-finishing period.

$$\mathrm{F} = \mathrm{IF} + \sum_{1}^{T} \mathrm{FTG}_t, \tag{2-14}$$

where IF is the initial fat weight of feeder pig (grams), which can be estimated by subtracting the initial carcass fat-free lean weight of feeder pig, IFFL, from the initial carcass weight of feeder pig. In this study, the initial body weight of the feeder pig is assumed to be 20000g (or 20 kg). The initial carcass weight can be estimated by dividing initial body weight by 1.35 (Swine Contract Library, 2004). That is,

$$\mathrm{IF} = 2000/1.35 - \mathrm{IFFL}\,. \tag{2-15}$$

The whole body protein gain, $\mathrm{WBPG_t}$, can be converted to the protein tissue gain in grams per day, $\mathrm{PTG_t}$ by a coefficient of 0.23;

$$\mathrm{PTG_t}(g) = \mathrm{WBPG_t} / 0.23\,. \tag{2-16}$$

Daily Weight Gain

The relationship between body water and fat is not statistically significant (Pomar *et al*., 1991). Body water and ash generated in the growth processes are more closely related to body protein synthesis. The coefficient converting protein retention into body mass is about four times greater than the coefficient converting lipid retention into body mass. This coincides with the finding of Fawcett et al. (1978). The daily body weight gain (grams per day), $\mathrm{DBWG_t}$, is then the sum of daily protein tissue gain and daily fat tissue gain divided by 0.94 to account for the other parts of the body weight gain, such as bone and skin.

$$\mathrm{DBWG_t}(g) = (\mathrm{PTG_t} + \mathrm{FTG_t}) / 0.94\,. \tag{2-17}$$

The body weight on the next day is the current body weight plus the current body weight gain, $\mathrm{DBWG_t}$; that is,

$$\mathrm{BW_{t+1}}(\mathrm{kg}) = \mathrm{BW_t} + \mathrm{DBWG_t}\,. \tag{2-18}$$

The simulation model that predicted pig growth then can be used to estimate energy, amino acid, calcium, and phosphorus requirement for maintenance and growth at each body weight. In addition, the simulation models of pig growth can be used to generate the estimates of nutrient requirements for pigs under various conditions. The predicted body weight by the growth model can be used to estimate amino acid and phosphorus requirements on the daily basis for pigs with a different lean growth rate, or housed under various temperature environments over the whole feeding period.

The Estimated Nutrient Requirements

Amino Acid Requirements

The nutritional constraints used in the model were also from the NRC. The requirements of lysine, the most limiting essential amino acids, consisted of those required for maintenance and those for protein deposition. The true ileal digestible lysine required for maintenance (LysineM) expressed in grams per day at any body weight is

$$\text{Lysine for maintenance (LysineM, g/day)} = 0.036 \times BW_t^{0.75} \qquad (2\text{-}19)$$

Table II-1 shows the ideal protein system in which requirements for each of the other amino acids are expressed as percentages relative to the lysine requirement for maintenance. Multiplying the estimated lysine requirement by the ratio of each amino acid to lysine in the ideal protein system gives the requirements for all the remaining essential amino acids

The daily amount of lysine needed to support protein accretion is the amount of true digestible lysine needed for each gram of protein accreted multiplied by the daily amount of whole-body protein. Using data from a wider range of experiments, the NRC (NRC, 1998) provided the estimated lysine requirement above maintenance for whole-body protein accretion as follows:

$$\text{Lysine for gain (g/day)} = 0.12 \times \text{WBPG}_t, \tag{2-20}$$

where lysine for gain is the daily requirement for true ileal digestible lysine intake above maintenance in grams, and WBPG_t is daily protein deposition in the whole-body in grams. The requirements of the essential amino acids other than lysine for protein deposition can also be calculated by using the ideal protein system in which requirements for each of the other amino acids are expressed relative to the lysine requirement for protein accretion.

The lysine requirement for protein accretion determined from the equation above is added to the maintenance requirement for lysine to obtain the total daily lysine requirement (LysineT). That is,

$$\begin{aligned}\text{Total lysine requirement (LysineT, g/day)} \\ &= \text{Lysine for maintenance} + \text{Lysine for gain} \\ &= 0.036 \times \text{BW}_t^{0.75} + 0.12 \times \text{WBPG}_t \end{aligned} \tag{2-21}$$

Total requirements for the essential amino acids other than lysine can also be calculated by adding those for maintenance with those for protein accretion.

Table II-1. Ideal Rations of Amino Acids to Lysine for Maintenance and Protein Accretion

Amino Acid	Maintenance, AAm(I)	Protein Accretion, AAp(I)
Aginine	-2.00	1.00
Histidine	0.32	0.48
Lysine	1.00	0.32
Tryptophan	0.26	0.54
Phenylalanine	0.50	1.02
Phenylalanine+Tyrosine	1.21	0.27
Methionine	0.28	0.55
Methionine+Cystine	1.23	0.60
Threonine	1.51	0.93
Leucine	0.70	0.60
Isoleucine	0.75	0.18
Valine	0.67	0.68

SOURCE: NRC, 1998.

Mineral and Vitamin Requirements

The NRC (1998) also provided estimates of daily mineral and vitamin requirements for average pigs under average conditions. The estimates of mineral and vitamin requirements at various body weights of growing pigs can be generated with the growth model. An exponential equation used to estimate the phosphorus requirements on a dietary concentration basis (percent of the amount of feed consumed) is given as follows.

$$\mathrm{Re}q.Concentration = EXP(-0.0557 - 0.416\ln BW + 0.005\ln BW^2), \qquad (2\text{-}22)$$

where BW is body weight.

Phosphorus Requirements

The energy and nutrient contents of feedstuffs determine the amount of feed required. Feedstuffs in least cost feed ration may be changing as the relative price of feed changes. Dietary phosphorus requirements calculated as a percentage of the diet may be dependent on feed intakes and energy density of diets. NRC recommends higher dietary concentrations of phosphorus, if feed intake is low. This advice suggests that phosphorus requirements are not only proportional to the feed intake, but also have their specific daily amounts (g/day).

Since feed ingredients, and thus feed intake may be changing in the profit maximization problem, the phosphorus requirements may be obtained by multiplying the estimated phosphorus concentration in a diet by the feed intake.

Equation (2-4) describes DE intake at each body weight. In the NRC model, the requirements for energy and nutrients are supplied based on a fortified corn-soybean meal diet with a constant DE content, 3.4 (kcal/g). Therefore, the estimated feed intake for pigs of various body weights is

Feed intake (g/day)= DE intake/3.4

The daily requirements (g/day) for bio-available phosphorus (PHR) were then calculated by multiplying the predicted dietary concentrations of phosphorus by the daily feed intake based on the fortified corn-soybean meal diet. That is,

$$\begin{aligned}
&\text{Daily P Requirements (PHR, g/day)} \\
&= \text{Req. Concentration} \times \text{Feed Intake (g)} \\
&= \text{Req. Concentration} \times (\text{Maximum DE intake}/3.4) \\
&= e^{-0.0557-0.416(\ln BW)+0.005(\ln BW)^2} \times 13162 \times (1-e^{-0.0176BW})/3.4
\end{aligned} \quad (2\text{-}23)$$

since the DE content of the diet formulated by the NRC is a fixed constant at 3.4 kcal/g. The dietary intake restriction was primarily an energy restriction (Calabotta et al., 1982). The proportion of ingredients were changed to maintain the same daily intake of protein, minerals, and vitamins for *ad libitum* and limit-fed pigs. Therefore, the phosphorus requirements for maximum growth rate recommended by the NRC were used as the phosphorus requirements, though the growth rate may be restricted in the profit maximization model.

The Simulation Result of the NRC Model

The data set used by the NRC as the source of information to estimate the parameters of biological functions that regulate pig's growth and nutrient requirements was from a vast literature survey. The *Swine Nutrition Guide* therefore provides an excellent basis for the prediction of animal's growth and the estimation of the energy and nutrients for maintenance and growth. The growth model for a potential (maximum) performance was simulated with a spreadsheet. The potential performance is defined as the maximum performance level that can be achieved by a specific strain under free feeding (*ad libitum*) conditions, while satisfying all nutritional requirements. The above constructed simulation model was used to predict body composition and body weight during the growth period, starting from a body weight of 20 kg. Pig's genotype and temperature are treated as input variables in the model.

Skipping the effects of temperature (assuming that the ambient temperature is $20^{0}C$), Appendix Table A-1 shows the detailed predicted result for potential growth on a daily basis by the simulation model. It delineates body weight, daily weight gain, whole body protein accretion rate, protein tissue accretion rate, and fat tissue accretion rate that can be achieved by mixed-sex pigs of high-medium lean growth rates with carcass fat-free lean gains averaging 325 g/day under free feeding programs, assuming all nutritional requirements were satisfied. Pigs steadily increase their body weight. Those with high-medium lean growth rate can achieve 120 kg body weight in 93 or 94 days. The predicted lean percentage in carcass would be 48 percent.

Lysine is generally regarded as the first limiting amino acid in cereal-based diets for growing pigs (NRC, 1998). Appendix Table A-2 shows the estimated energy and lysine requirements on a daily basis associated with potential growth by the simulation model. It can be been seen that daily digestible energy, lysine, and bio-available phosphorus required for maintenance and growth increase as the animals increase their body weight.

Figures 2-1 to 2-4 show the effects of the ambient temperature on growth level, body weight, fat tissue accretion rate, protein tissue accretion rate, and daily carcass fat free lean gain. In the simulation model, the temperature and genotype are two external factors that determine the protein accretion rate given a particular DE intake. The temperature was specified at $15^0 C$ $20^0 C$, and $25^0 C$ in whole body protein generating equation for simulation strategies. Pigs tend to steadily increase their body weight during the feeding period. As the temperature decreases, pigs increase their body weight more quickly. However, pigs fed at the low temperature environment tend to have smaller fat tissue accretion rate, and significantly higher protein accretion rate. Figure II-4 shows that a low temperature environment largely increase daily carcass fat free lean gain. The lean percentage in carcass increases from 48 percent to 51 percent as temperature decrease from 20^0C to 15^0C. The lean percent in carcass decreases from 48 percent to 45 percent as temperature increase from 20^0C to 25^0C.

Accompanying the higher growth rate, DE and lysine requirements also increase as the ambient temperature decreases. Figure II-5 and 2-6 show that both DE intake and DE requirements for maintenance increase, as temperature falls. Lysine requirements for growth largely increase, as temperature falls. However, the requirements for bio-available phosphorus do not increase as much as temperature falls. For every 5^0C decrease in temperature, the requirements for bio-available phosphorus increase by 0.46 percent.

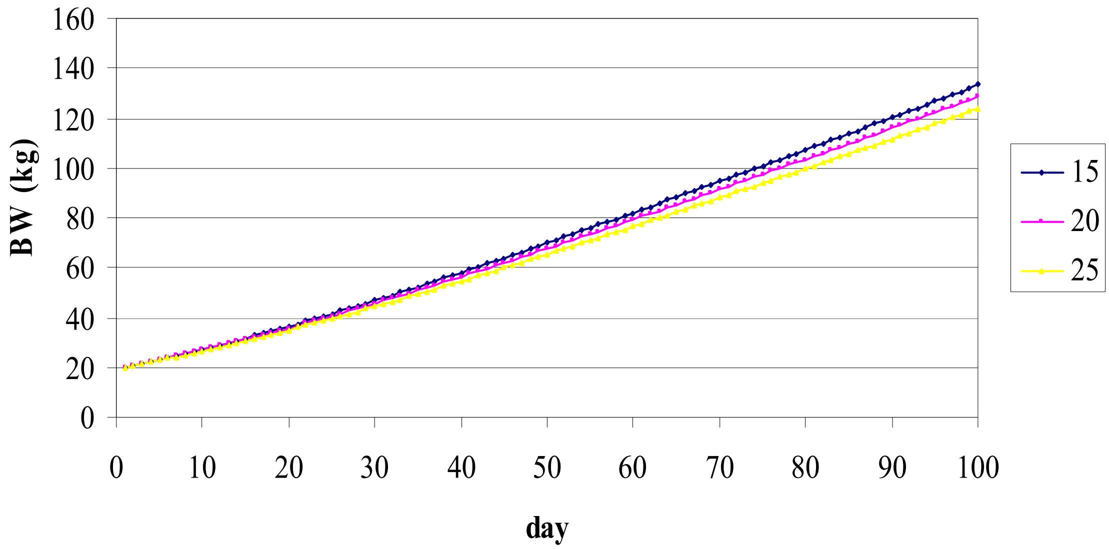

Figure II-1. The Effects of Temperature on Body Weight

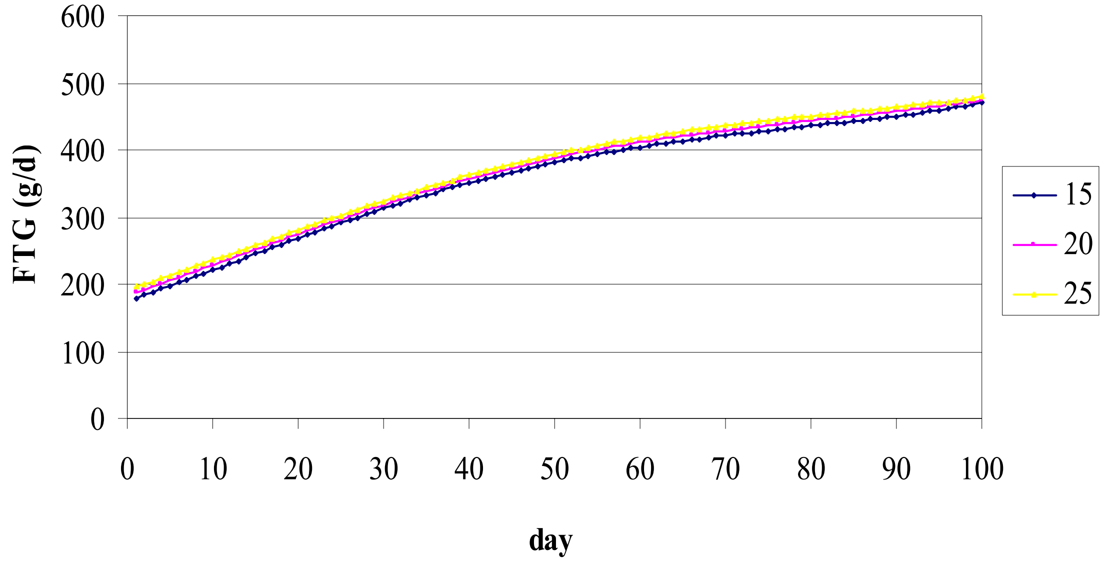

Figure II-2. The Effects of Temperature on Fat Tissue Gain

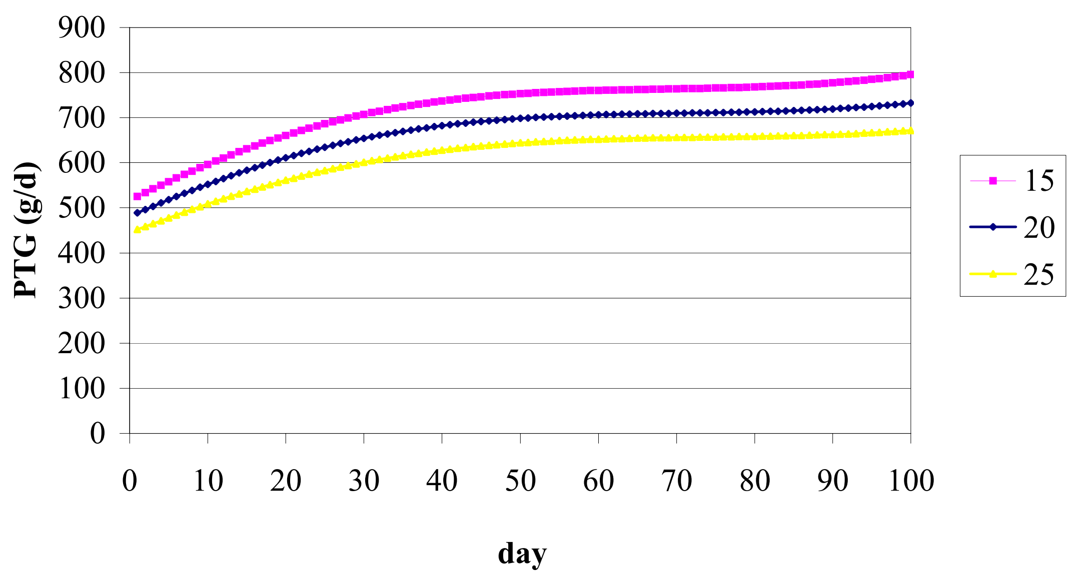

Figure II-3. The Effects of Temperature on Protein Tissue Gain

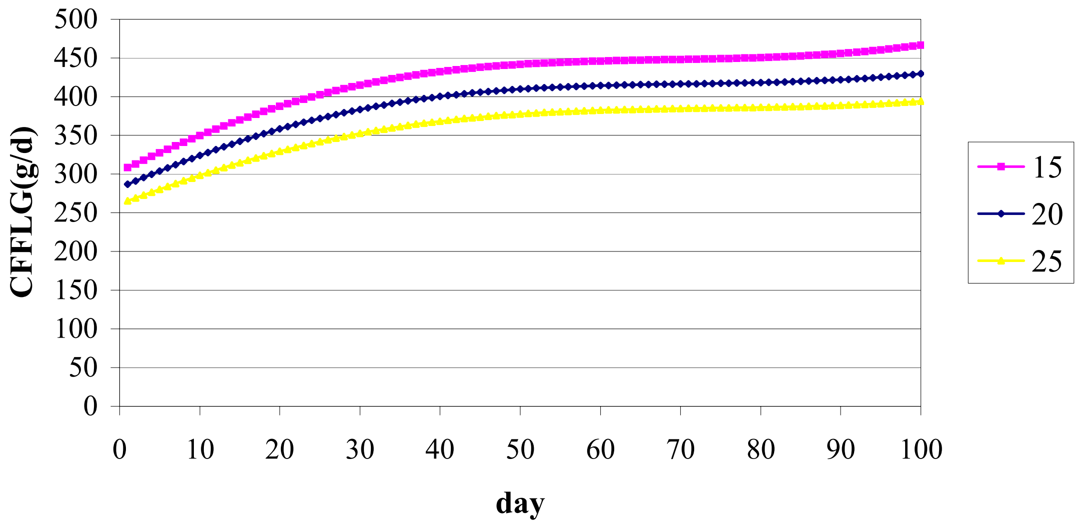

Figure II-4. The Effects of Temperature on Carcass Fat Free Lean Gain

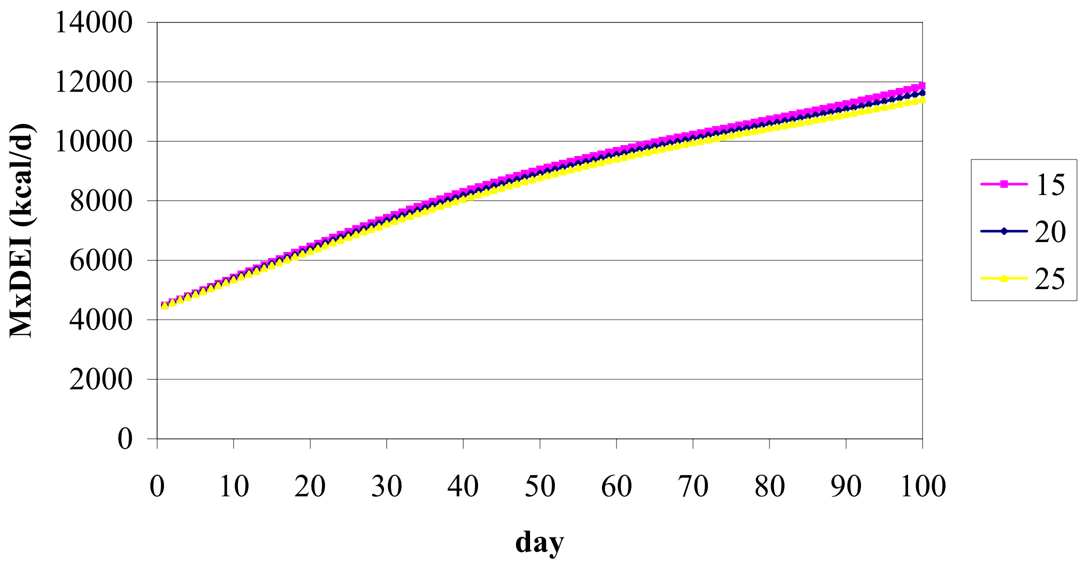

Figure II-5. The Effects of Temperature on Maximum DE Intake

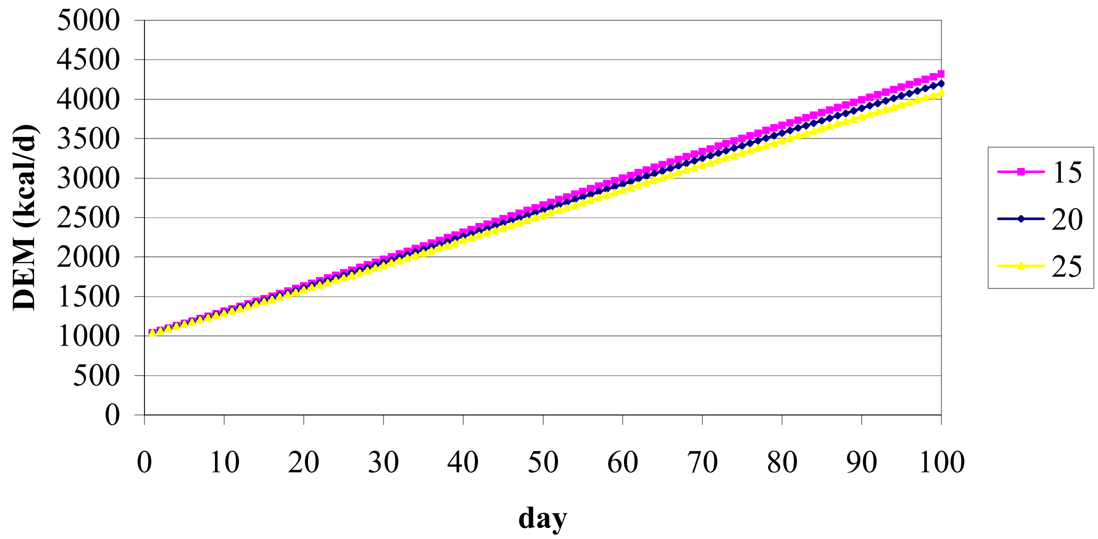

Figure II-6. The Effects of Temperature on DE Requirement for Maintenance

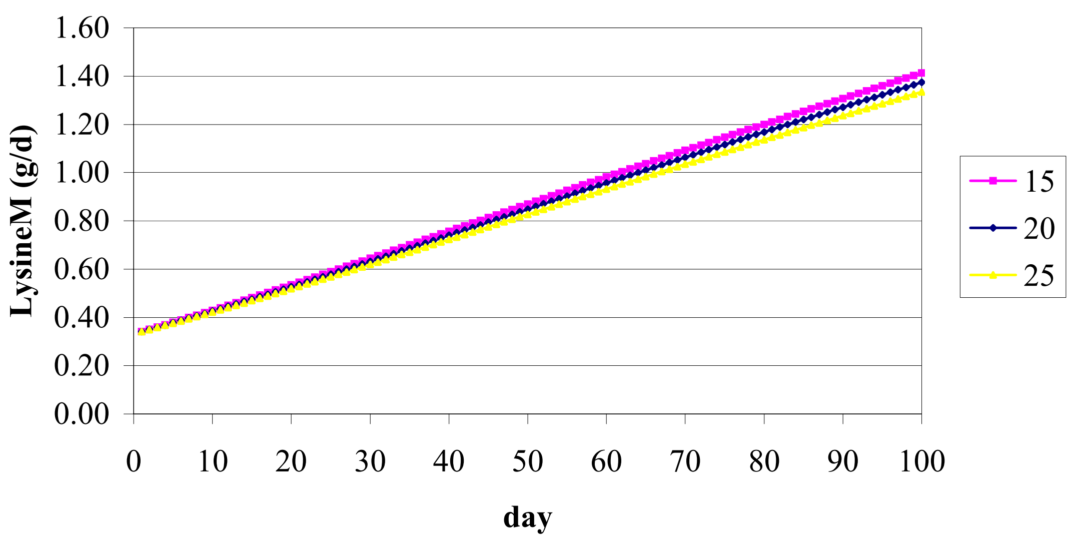

Figure II-7. The Effects of Temperature on Lysine Requirement for Maintenance

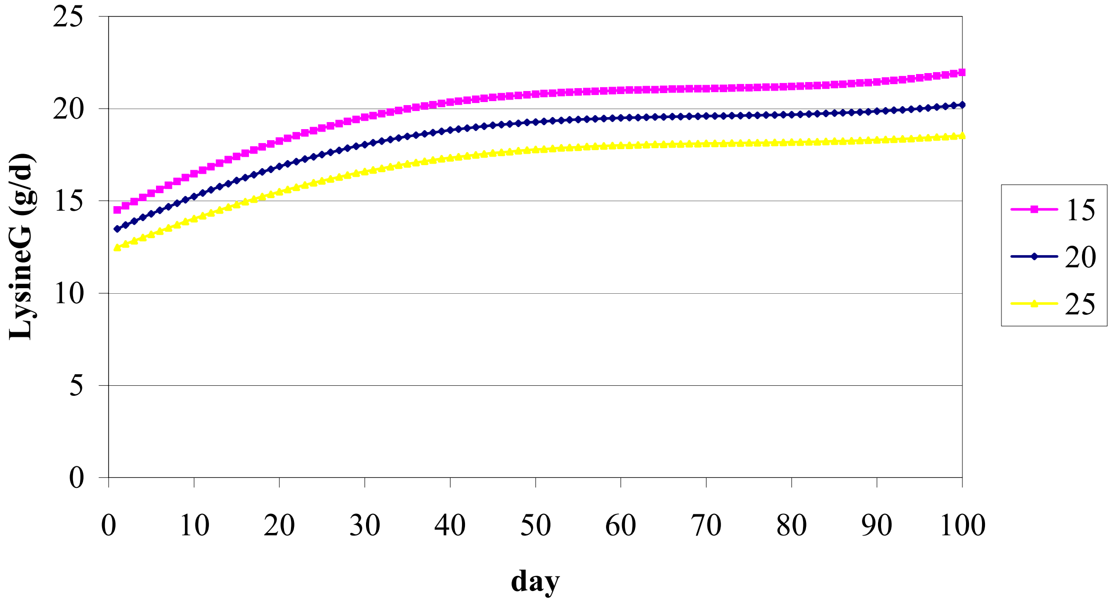

Figure II-8. The Effects of Temperature on Lysine Requirement for Growth

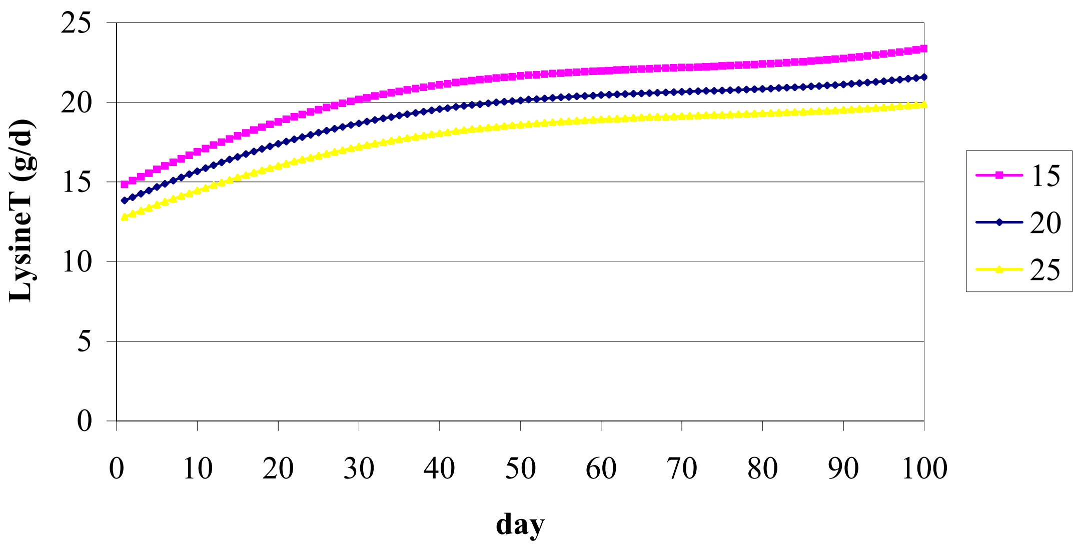

Figure II-9. The Effects of Temperature on Total Lysine Requirement

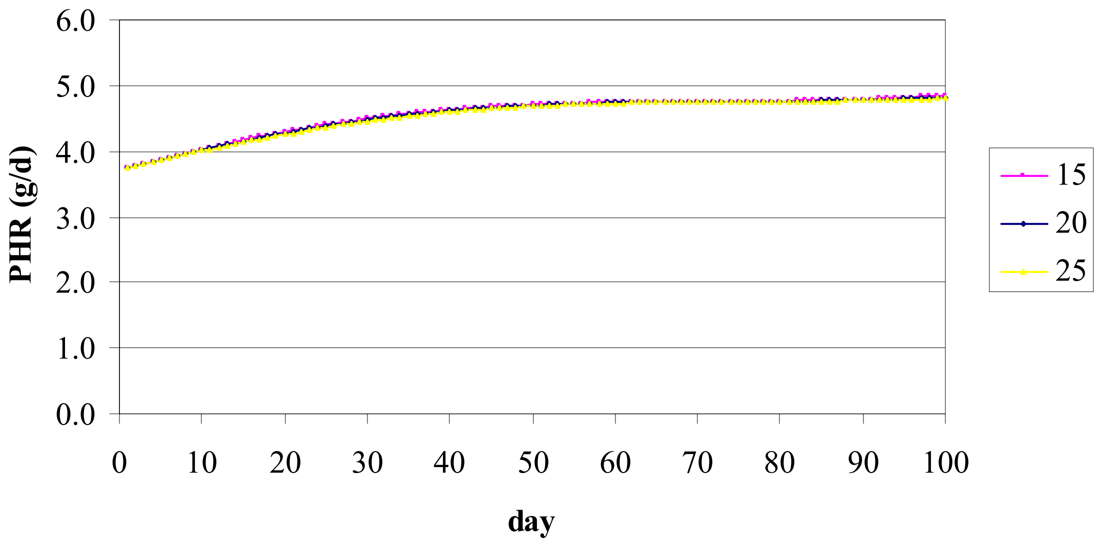

Figure II-10. The Effects of Temperature on Phosphprus Retention

Figures 2-10 to 2-13 show the generic effects on growth level; body weight, fat tissue accretion rate, protein tissue accretion rate, and daily carcass fat free lean gain. Given a particular DE intake, the genotype that determines the lean growth rate also affects the protein accretion rate. The mean fat-free carcass lean accretion rates (MFFL) were specified to be 300, 325, and 350 grams per day in the whole body protein generating equation for simulation strategies. Pigs steadily increase their body weight during the feeding period. As genotype improves, pigs tend to increase their body weight more quickly. However, pigs with high potential of lean growth rate tend to have smaller fat tissue accretion rate, and significantly higher protein tissue accretion rate. Figure II-13 shows that pigs with higher genetic potential for growth have higher daily carcass fat free lean gain. The lean percentage in carcass increases from 45 percent to 48 percent as the lean growth rate improved from 300 to 325. The lean percent in carcass increases from 48 percent to 51 percent as the lean growth rate improved from 325 to 350.

Accompanying the higher growth rate, DE and lysine requirements also increase as genotype was improved. Figure II-14 and 2-15 show that both DE intake and DE requirements for maintenance increase, as genotype was improved. Lysine requirements for growth increase, as the growth genotype was improved. However, the requirements for bio-available phosphorus do not increase much as the potential to increase lean growth rate increases.

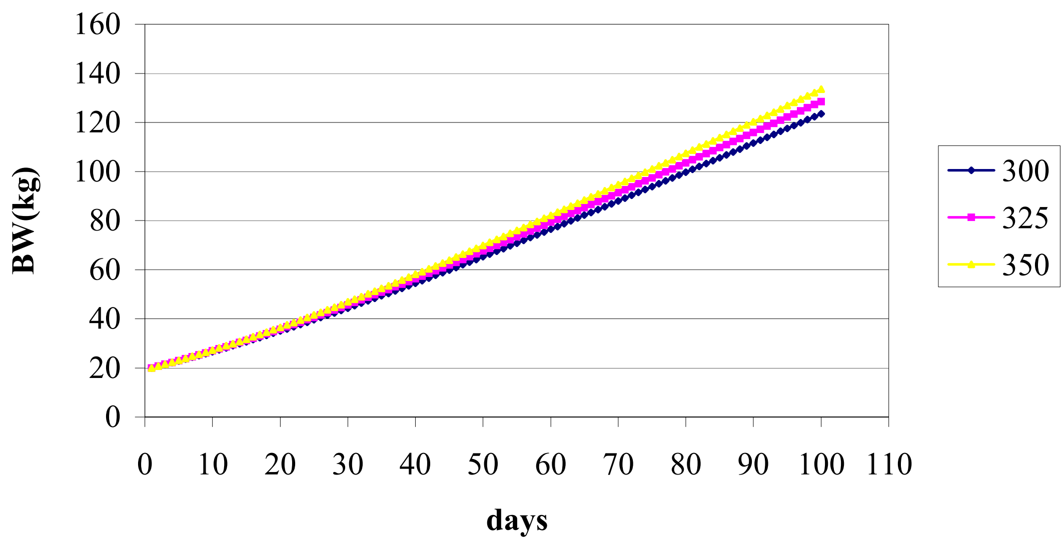

Figure II-11. The Effects of genotype on Body Weight

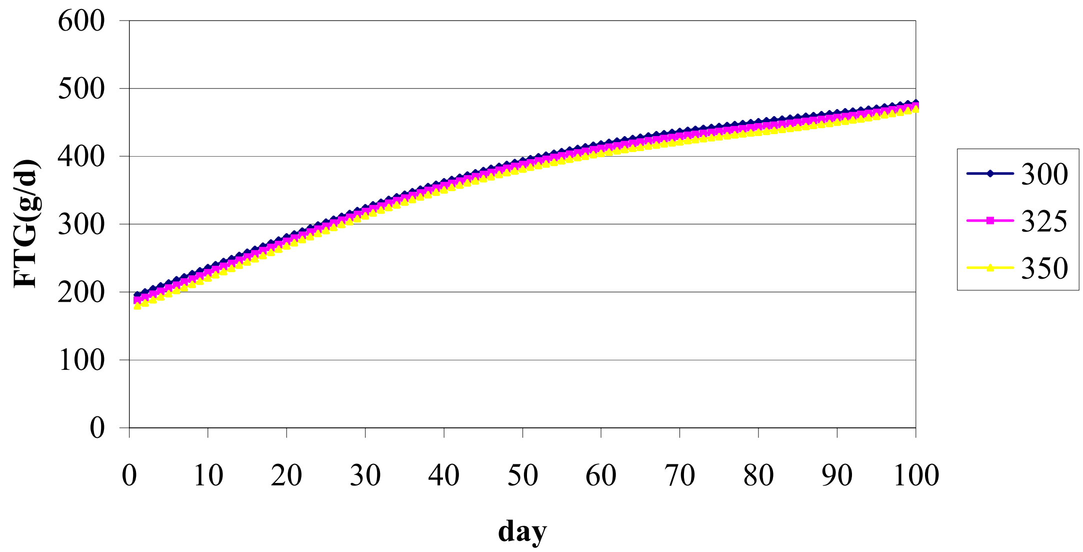

Figure II-12. The Effects of Genotype on Fat Tissue Gain

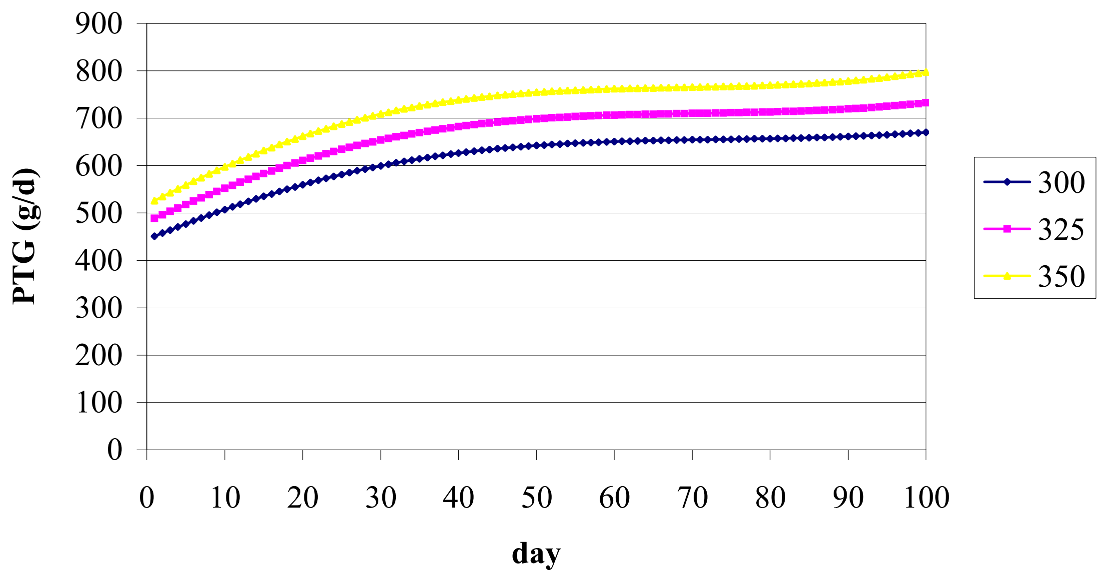

Figure II-13. The Effects of Genotype on Protein Tissue Gain

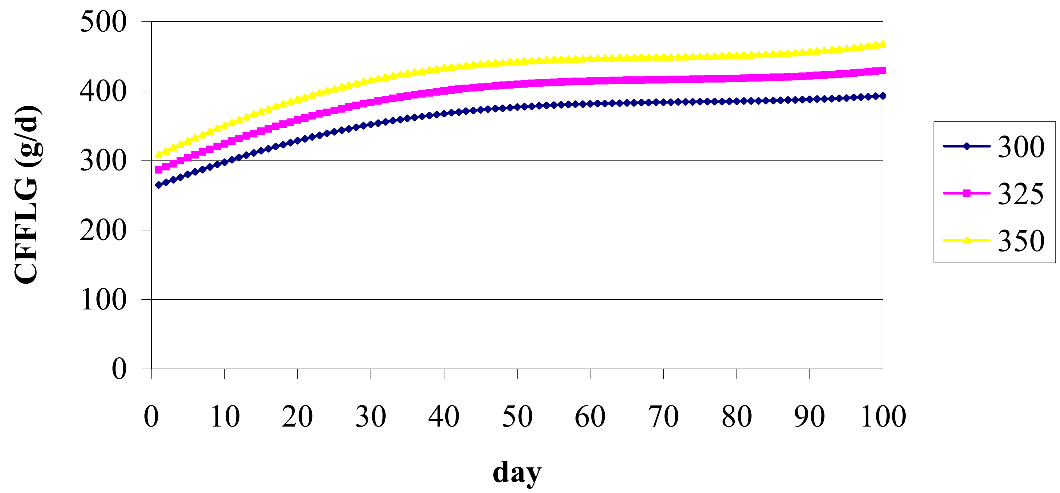

Figure II-14. The Effects of Genotype on Carcass Fat Free Lean Gain

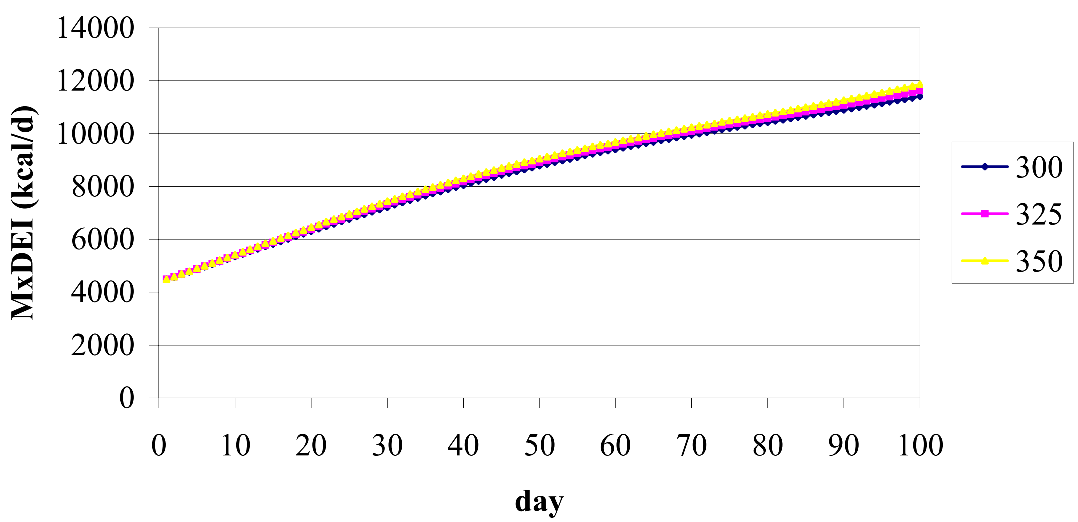

Figure II-15. The Effects of Genotype on Maximum DE Intake

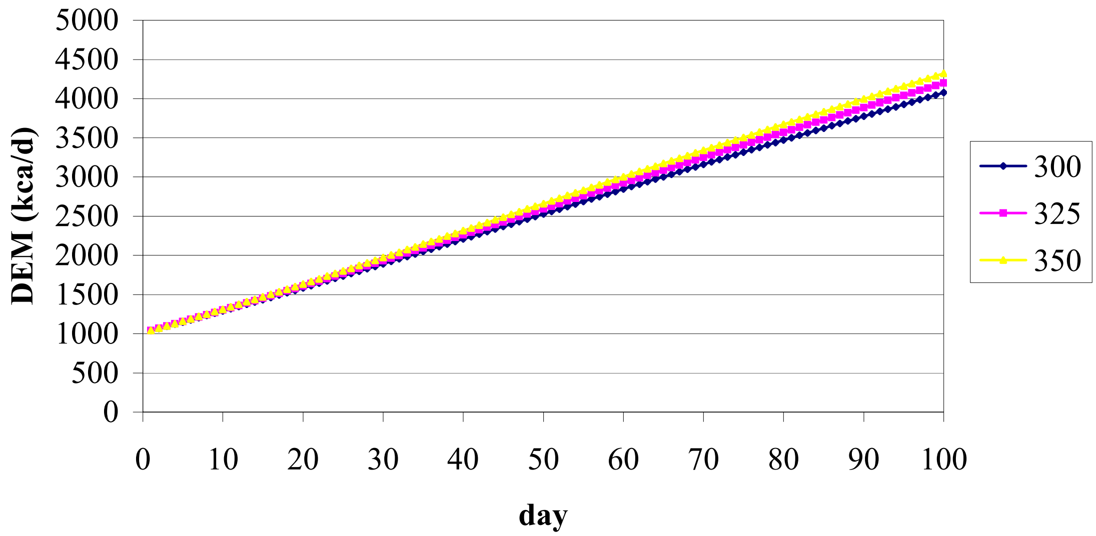

Figure II-16. The Effects of Genotype on DE Requirement for Maintenance

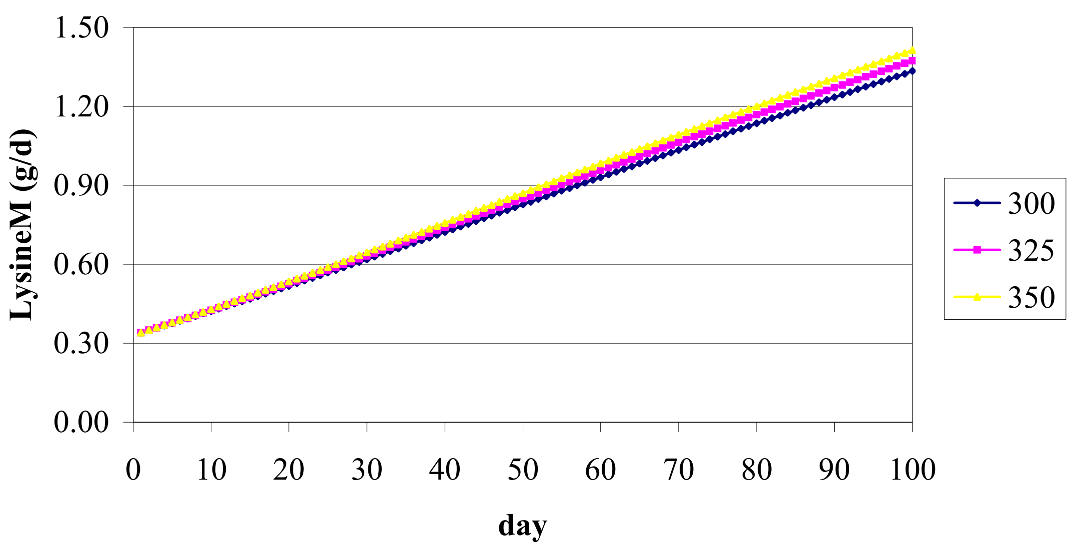

Figure II-17. The Effects of Genotype on Lysine Requirement for Maintenance

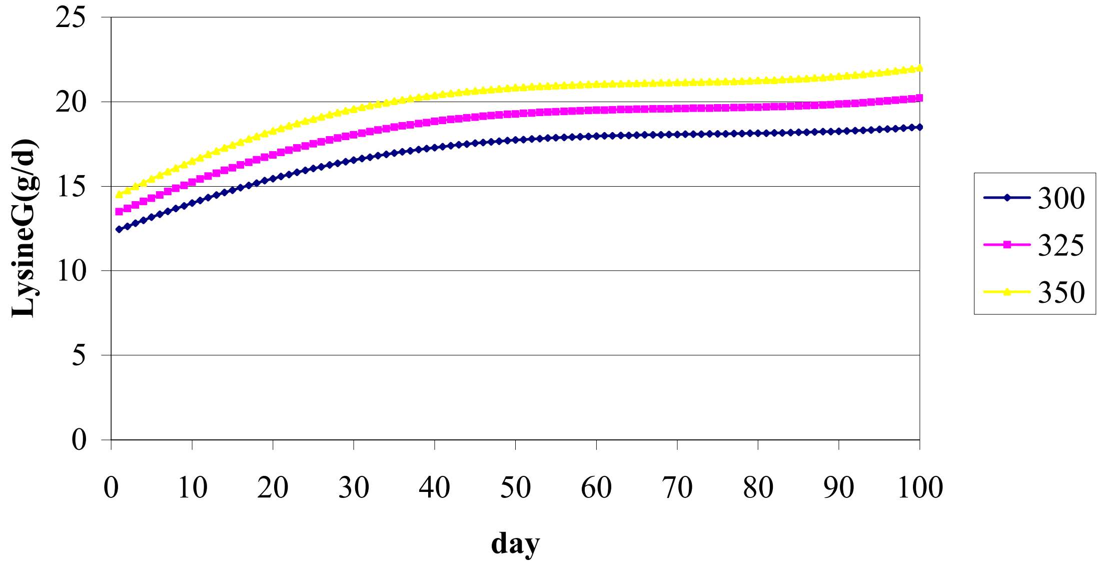

Figure II-18. The Effects of Genotype on Lysine Requirement for Protein Growth

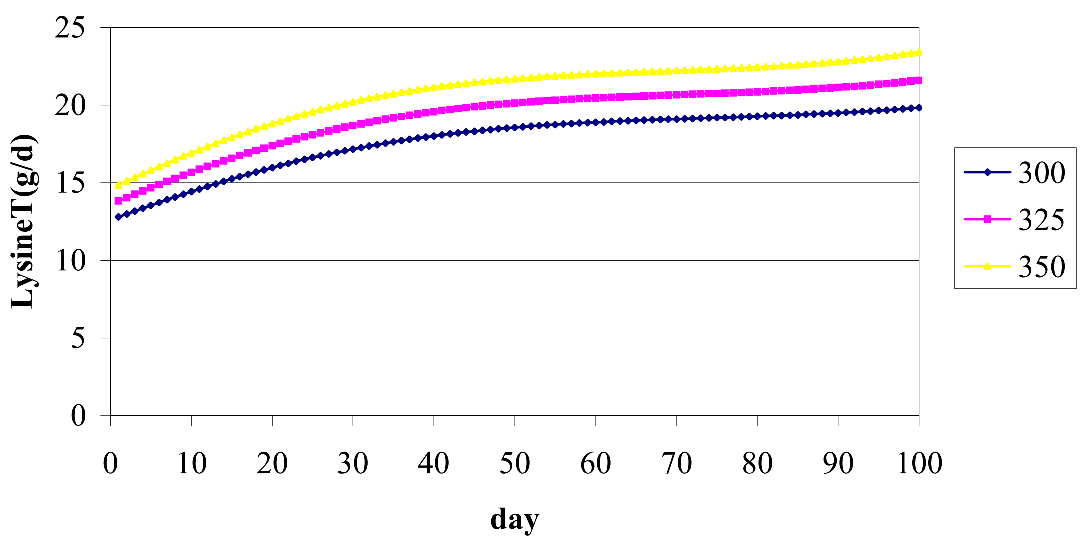

Figure II-19. The Effects of Genotype on Total Lysine Requirement

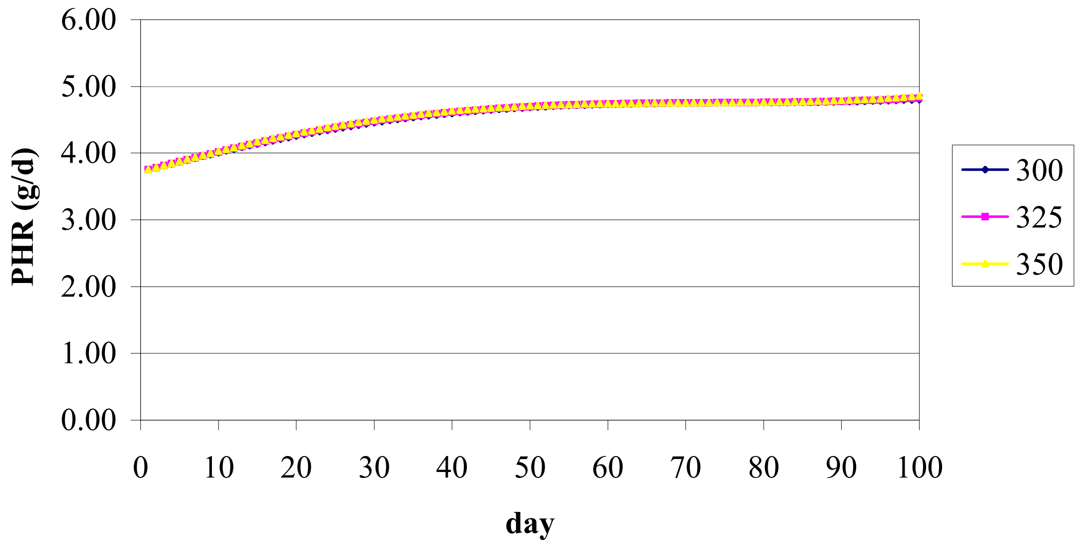

Figure II-20. The Effects of Genotype on Phosphorus Retention.

Similar simulation models of pig growth also appear in other research. Using biological data, Whittemore and Fawcett (1976) constructed a growth model in which the isoquant and isocomposition functions were mapped into a diet space with daily digestible energy intake and daily digestible protein intake as the axes. Desired daily body weight gain and composition of the gain thus can be simultaneously determined by manipulating nutrient content in diets. In their model, daily body weight gain consisted of protein retention and lipid retention. The total protein synthesis was equal to the sum of new synthesis and re-synthesis. Digested protein was used for new protein synthesis. Protein requirements for maintenance represented the endogenous loss on protein turnover. Since body water and ash are closely related to body protein synthesis, the least cost gain is that which tends to maximize protein deposition. Fawcett et al. claimed that diet with the minimum protein and energy content to attain the maximum daily rate of protein deposition represents the biologically most efficient growth at a particular live weight. However, Fawcett's model is more empirical and is of restricted use for decision analysis in hog production. Factors determining protein accretion and subsequently, growth efficiency are limited to nutritional means. Unlike NRC model, variations in genotype and ambient temperature were not included in the analysis. In the NRC model, the biological processes that described energy and protein metabolism or regulated protein synthesis were incorporated in the whole body protein generating equation. Those concepts were not seen in Fawcett et al.'s model.

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CHAPTER III

THE PROFIT MAXIMIZATION PROBLEM OF SWINE PRODUCTION

Maximization of Profit VS Maximization of Gain

The main goal of diet formulation and feeding strategy of the modern commercial pig production should be to maximize profit rather than to maximize animal performance. The profit maximization problem is based upon the assumption that growth response to nutrient input follows the principle of diminishing returns (Park, 1970, 1982; Gahl et al., 1995). Increment in gain decreases as equal increments of nutrients are added to the diet. Since animals grow at a decreasing rate in response to equal increase in energy and nutrient intake, diminishing returns to additional nutrient inputs occur as the maximum response is approached. With diminishing returns from additional nutrient inputs, the maximum profit of hog production occurs at the nutrient levels, where the benefit of weight gain by adding a unit of nutrient is equal to the nutrient cost incurred from adding that unit of nutrient. Diets containing more energy and nutrient than the profit maximizing levels result in reduced profits, because the benefit of adding a unit of nutrient is smaller than the cost of providing that unit of nutrient. On the other hand, increasing energy and nutrient in the diets containing lower energy and nutrients than the profit maximizing levels would increase profits, because the benefit of adding a unit of nutrient to diets is greater than the cost of providing that unit of nutrient.

The profit maximizing gain usually occurs before animals reach their maximum gain, because the benefit of adding additional units of a nutrient increase at a diminishing rate, so the cost of maintaining or increasing the rate of gain increases at an increasing rate as the animal reaches maximum performance. Although diets formulated for the maximum performance may also result in minimum feeding cost as the prices of feedstuffs and other inputs change, diets formulated with the principle of diminishing returns will be more efficient in term of their capacity to adjust production in response to those changes in the relative prices of pork or feed. As feed cost was estimated to be 55 to 70 percent of the total cost of pork production (Fact Sheet-3500, Oklahoma Cooperative Extension Service), diets formulated using diminishing returns concepts may result in greater profits than diets formulated for maximum gain.

Manipulating the diet by the concepts of diminishing returns incorporates price parameters into the decision analysis of growth variables and feed ingredients. Information about hog prices, therefore, is important for swine production. The equilibrium hog prices generally consist of two components, market prices and transaction prices that fluctuate around the market price levels (Ward et al., Fact Sheet-551). The general price levels in the hog market are dependent on the relative position of aggregate supply curve and demand curve, which in turn are affected by price determination factors. Factors that affect the amount of pork supplied include the price of pork, input (feeder pig and feed) cost, and technological advancement (improvement of generic potential for lean growth). Factors that affect the quantity of pork demanded include the price of pork, prices of substitute products (beef, veal, and poultry), consumer income, and changes in consumer preferences and tastes. In fact, supply and demand conditions in the hog market interactively determine the market price levels. When the demand for pork declines, downward shift in the demand for pork relative to current supplies results in a low price level. When pork supplies are expanding, large supplies of hog relative to consumer demand also results in a low price level.

Market Price for Carcass Quality

Transaction price is defined as the price level at which buyers and sellers negotiate to arrive for a given quality and quantity of a product at a given time and place (Ward et al, 1996). Transaction prices that result from price discovery process generally fluctuate around market prices. Some discovery factors, such as market structure, the amount and type of available market information for publics, futures markets, and risk management alternatives might affect the aggregate transaction price level (Ward et al., Fact Sheet-551). However, price differences between individual pigs are mainly attributable to the quality of the pig brought to market. In fact, since 1990s, hog transaction prices have been increasingly dependent on carcass characteristics rather than live weight. Carcasses with desirable characteristics, such as high percentages of lean meat, and low percentages of fat is evaluated as high class, and can be sold for higher price. On the other hand, those with undesirable carcass characteristics, such as low percentages of lean meat and high percentages of fat, only have low values. However, because of asymmetry information and uncertainty about carcass characteristics in hog markets, buyers and sellers can only discover prices with the market price levels.

The pig production industry in Oklahoma is currently dominated by very large hog operations. The prevailing structure of pig production industry has affected the way hogs were marketed. As pig production farms enlarged in size, securing and expanding a market for hogs produced have become increasingly important. As a result, contracting and packer ownership both became more prevalent during 1990s. Survey results complied by University of Missouri and Iowa State University showed that marketing contract usage grew dramatically during the last decade (Schroeder et al., 2004). Lawrence et al (2001), summarizing marketing patterns, suggested that during 2000, 70 percent of all hogs marketed in the United States that year were sold via contract in contrast to 57 percent in all hogs marketed that were sold via contract during 1997.

As market contracts and packer-ownership of hogs become two increasingly common ways of marketing hogs in the U.S., price discovery process is more important for determination of hog price. Traditionally most hogs in the United States were sold via a live weight pricing system. For example, in 1992, 92 percent of the U.S. hogs were sold in the market that does not consider carcass characteristics when pricing hogs (Schroeder et al., 2004). Revenue from hog production was calculated by multiplying the unit price by the body weight of hogs. Carcass quality played no role in determining hog prices. As a result, consumers had once perceived carcasses as being too fat. As all efforts were made by large contractors to increase consumer demand and ensure repeated purchase, pig production was directed to be more market oriented. The increasing consumer preference for lean pork, therefore, provided an incentive for industry to establish the carcass merit pricing systems that to provide premiums to pigs possessing desirable carcass traits, or discounts to those with undesirable carcass traits. Under the merit pricing systems, each pig carcass was valued individually and thereby there exists the opportunity for packers to send economical signals to producers to supply lean pork that meets the market demand. As technology continues to make progress, more electronic instrumentation is now available for packing plants to quantify carcass lean-meat percentage (LP). Lawrence and Grimes (2001) estimated that during 2000, large operations, marketing more than 50,000 head per year, sold over 97 percent of their finished pigs via carcass merit pricing systems (Schroeder et al., 2004). The phenomenon of nation-wide establishment of carcass merit pricing programs may demonstrate the trend that hog quality plays an increasingly important role in hog price formation, and may be used to explain the fluctuation in hog prices around the same market price levels.

Other input costs, such as feeder-pig and feed costs, are assumed exogenously determined and known with certainty. This assumption is reasonable in the grain markets where trading with future contracts is popular.

Pork Value under the Carcass Merit-Pricing Program

Under the carcass weight and merit-pricing program, buyers bid and sellers offer different prices to negotiate an acceptable price by using available information on the demand and supply conditions of the hog market. The net price received for each hog is a base price plus a discovered price. The base price is the general market price level that is determined by the intersection of estimated supply and demand curves on each given day, while the discovered price is the carcass quality premium or discount for desirable and undesirable carcass traits, which are judged by pig's final body weight and carcass lean percent. The discovered price generally fluctuates above and below the market price. The equilibrium hog price, P_h, is therefore dependent on final body weight and lean percent in carcasses (LP); i.e.

$$P_h = P_b \times U(FBW, LP), \tag{3-1}$$

where FBW is the final body weight in kilogram; P_b is the base hog price per kg; and $U(\cdot)$ is the net carcass quality premiums (discounts) rates expressed as the percentage of base hog price for desirable (undesirable) carcass traits, such as final body weight and lean percent; LP is the lean meat percent in carcasses.

In the carcass merit pricing systems, a base price for a transaction is usually tied to an external reference price (Schroeder et al., 2004; Fact Sheet-573, Oklahoma Cooperative Extension Service). Wholesale pork cutout prices were generally regarded as the best external reference price in formula pricing of hogs. Wholesale pork cutout prices can well reflect the true carcass value, because a profit-maximizing packer would sell pork production for as high a price as possible. As producers have incentives to keep pork cutout price as high as possible, tying the base price to the pork cutout price would be a fair deal for producer. In contrast, tying the base price to the historical hog price will provide incentives for packers to report hog prices as low as possible to minimize their input costs, and to undervalue the carcass values. Another advantage of using the composite wholesale pork cutout price as the base price in carcass merit pricing systems is the pork cutout price are reported by USDA and readily available. Wholesale pork cutout prices also reveal more consumer preference and thus, are good sources of inference price for the base price.

Empirical estimation of the carcass weight and merit-pricing system with available data are almost impossible. The hog price information currently reported by USDA is not adequate for explaining and analyzing the relationship between the quality of a particular hog, and the corresponding base price and premium/discount schedule. The weighted-average base prices of hogs with their associated price ranges that are published for all five marketing arrangements in the USDA's National Daily Direct Prior Day Hog Report were calculated from all traded hogs with different carcass qualities. That is, the reported base prices calculated by USDA may also contain information related to premium/discount rates. Since the effects of differences in prices paid for similar quality hogs on the weighted-average base prices can not be separated from that caused by differences in hog quality, the price variation in USDA's report may not be appropriate to be linking to the base prices of carcass weight and merit-pricing program as an external reference price.

The Swine Contract Library (http://scl.gipsa.usda.gov/) is another data source providing information helpful to facilitate the price discovery process. In addition to a listing of the variety of base prices currently being used by pork packers, the Library also contains a variety of hog carcass price premium and discount matrices. Table III-1 shows one example of hog carcass price premium and discount matrixes listed on the Swine Contract Library. However, despite the diversity of information contained in the Library, it does not provide further information for users to link the base price and the premium/discount matrix together. It is, therefore, impossible to obtain information on practical carcass weight and merit-pricing programs directly from the Library (Schroeder et al., 2004).

Table III-1. An Example of Premium and Discount Schedules (%)

LP (%)	Body Weight (kg)									
	95	97	102	106	111	115	120	155	159	162
63	77	92	94	97	99	100	101	94	92	77
62	78	93	95	98	100	101	102	95	93	78
61	79	94	96	99	101	102	103	96	94	79
60	80	95	97	100	102	103	104	97	95	80
59	81	96	98	101	103	104	105	98	96	81
58	82	97	99	102	104	105	106	99	97	82
57	83	98	100	103	105	106	107	99	98	83
56	82	97	99	102	104	105	106	99	97	82
55	81	96	98	101	103	104	105	99	96	81
54	80	95	97	100	102	103	104	98	95	80
53	79	94	96	99	101	102	103	97	94	79
52	78	93	95	98	100	101	102	96	93	78
51	77	92	94	97	99	100	101	95	92	77
50	76	91	93	96	98	99	100	94	91	76
49	76	91	93	95	97	99	99	94	91	76
48	75	90	92	94	96	98	98	93	90	75
47	74	89	91	93	95	97	97	92	89	74
46	73	88	90	92	94	96	96	91	88	73
45	72	87	89	91	93	95	95	90	87	72
44	71	86	88	90	92	94	94	89	86	71
43	70	85	87	89	91	93	93	88	85	70
42	69	84	86	88	90	92	92	87	84	69
41	68	83	85	87	89	91	91	86	83	68
40	67	82	84	86	88	90	90	85	82	67

Source: Swine Contract Library (http://scl.gipsa.usda.gov/).

Analyzing packer behavior might be helpful for constructing a carcass weight and merit-pricing program. A large number of premium/discount matrices on the Swine Contract Library show that premium/discount rates on live weight ranges maintain unchanging across various lean percent ranges. Table III-1, for example, shows that the premium/discount patterns for delivering an animal within a certain weight range are almost the same across different lean percent ranges. Therefore, it is reasonable to assume that schedules of premium/discount on live weight and lean percent ranges are mutually independent. That is,

$$U(FBW, LP) = U_w(FBW) \times U_l(LP) . \qquad (3\text{-}2)$$

Assuming that the schedules of premium/discount on live weight ranges are independent from those on lean percent ranges, a sample carcass merit-pricing program $U_l(LP)$ can be constructed as follows. Suppose that a packer sells her/his meat products in the wholesale pork market. The revenue the packer receives from meat production is equal to the sum of the prices the packer received for each meat products multiplied by the quantity of that product. Given a carcass with 51 percent lean meat, the revenue the packer receives from meat production is

$$0.51 \times \frac{FBW}{1.35} \times CLP , \qquad (3\text{-}3)$$

where $FBW/1.35$ is the carcass weight in kg; CLP is the composite lean meat prices (dollar per kg).

The revenue from selling meat products in the wholesale pork market was assumed not including the byproduct or fat value the packer receives. The meatpacker's revenue was fully represented by the boxed pork cutout value. Suppose that both packers and producers agree to tie the base price to the wholesale pork market price. The amount the packer is willing to pay for a carcass with 51 percent lean meat is the revenue from selling meat products in the wholesale pork market minus processing cost. This is expressed as a ratio, α. The use of ratio is intended to reflect slaughter costs, processing costs, and packer profit margin, as a fraction of the producer revenue. Thus, given the revenue from selling meat products in the wholesale pork market, the price paid to producers is the pork cutout value times α. So if the boxed pork cutout value is $0.51 \times (FBW/1.35) \times CLP$, the live hog price, $P_h = P_b \times U_1(LP)$, can be described as

$$FBW \times P_b \times U_1(0.51) = \alpha \times (0.51 \times \frac{FBW}{1.35} \times CLP). \tag{3-4}$$

A vast number of different premium/discount schedules on the Swine Contract Library show that corresponding discount rates to 51 lean percent in carcass within the weight range of interest are usually zero. Therefore, the price paid for carcass with 51 lean percent may be regarded as the base price with discount rate zero. That is,

$$\begin{aligned} P_b &= \alpha \times (0.51 \times \frac{FBW}{1.35} \times CLP)/FBW \\ &= \frac{\alpha}{1.35} \times (0.51 \times \frac{FBW}{1.35} \times CLP)/ \frac{FBW}{1.35} \\ &= \frac{\alpha}{1.35} \times (0.51 \times CLP) \qquad (3\text{-}5) \\ &= \frac{\alpha}{1.35} \times WPCP \end{aligned}$$

where WPCP is the wholesale pork cutout prices with 51 percent lean meat in carcass in dollars per kg.

Consider a carcass with 50 percent lean meat. Given the boxed pork cutout value of $(0.50 \times FBW/1.35) \times CLP$, the discount rate corresponded to 50 lean percent in carcass, $U_1(0.50)$ is

$$U_1(0.50) = \frac{\alpha}{1.35} \times (0.50 \times \text{CLP})/P_b$$

$$= \frac{\alpha}{1.35} \times (0.50 \times \text{CLP})/ \frac{\alpha}{1.35} \times (0.51 \times \text{CLP})$$

$$= 0.98 \tag{3-6}$$

Again consider a carcass with 52 percent lean meat. Given the boxed pork cutout value of $(0.52 \times \text{FBW}/1.35) \times \text{CLP}$, the discount rate corresponded to 52 lean percent in carcass, $U_1(0.52)$ is

$$U_1(0.52) = \frac{\alpha}{1.35} \times (0.52 \times \text{CLP})/P_b$$

$$= \frac{\alpha}{1.35} \times (0.52 \times \text{CLP})/ \frac{\alpha}{1.35} \times (0.51 \times \text{CLP})$$

$$= 1.02 \tag{3-7}$$

Table III-2 shows a complete list of calculated carcass value adjustment schedule for lean percent over the range of 63 percent to 40 percent. The calculated carcass value adjustment schedule for lean percent is approximately consistent with most of the hog carcass price premium and discount matrices listed on the Swine Contract Library. The analysis above illustrated how prices in wholesale pork market can be used in a base price formula. The base price in hog market is tied to wholesale pork cutout prices, meeting the expectation that the base price in the hypothetical carcass merit- pricing program should be linked to a separate but related wholesale pork market to reflect market conditions in formula pricing. The analysis of packer behavior also makes it possible to link base prices with the premium/discount schedule to construct a carcass merit-pricing program.

Table III-2. The Calculated Adjustment Schedule for Various Carcass Lean Percent

Lean Percent	Adjustment Rate
0.63	1.24
0.62	1.22
0.61	1.20
0.60	1.18
0.59	1.16
0.58	1.14
0.57	1.12
0.56	1.10
0.55	1.08
0.54	1.06
0.53	1.04
0.52	1.02
0.51	1.00
0.50	0.98
0.49	0.96
0.48	0.94
0.47	0.92
0.46	0.90
0.45	0.88
0.44	0.86
0.43	0.84
0.42	0.82
0.41	0.80
0.40	0.78

To estimate the net price the producer receives, the ratio of wholesale pork cutout value assigned to the producer must be examined. Equation (3-5) shows that the cash price the producer receives for a carcass with 51 lean percent are the wholesale pork cutout price times the ratio α. Ward et al. computed ratios between cash hog and wholesale pork market prices through the years from 1989 to 1998 (Fact Sheet-573, Oklahoma Cooperative Extension Service). The average value of the ratio between the cash hog and wholesale pork cutout prices is approximately 0.72. However, the observation that the ratios vary over the data period suggests that ratio may not be constant. Additional factors, such as byproduct value, slaughter costs, processing costs, and packer preference must be taken into account to determine the ratio value. Changes in byproduct value, slaughter costs, or processing costs might affect the profit margin packers receive. This creates incentives for both producers and packers to adjust cash-wholesale market price ratios used in formula pricing.

As slaughter cost, processing cost, or packer preference change, appropriate adjustments are necessary when computing a fixed cash-wholesale market price ratio. For example, a reduction in the cash-wholesale market price ratio is necessary for packers to cover increased processing cost when the lean percent in carcasses is reduced. As the lean percent in carcasses becomes lower, the carcass value should be adjusted downward by the adjustment schedule of Table III-2. However, this reduction in wholesale cutout values only reflects the reduction in pork cutout value due to lower carcass lean percent, and does not include rising cost for processing fatty carcasses. Given a fixed slaughter cost, the low lean percent carcasses also result in revenue loss relative to high lean percent carcasses so the wholesale cutout values adjusted by Table III-2 may overestimate the true value of pork at the wholesale level. Lower revenue would motivate packers to negotiate an adjustment on the ratio with producers. For example, if the ratio between the cash hog and the wholesale boxed pork cutout prices was 0.72 for a carcass with 51 percent lean, then the ratio for a carcass with 50 percent lean could be adjusted downward by a percentage (say 0.03 below the base ratio of 0.72, resulting in a ratio of

0.69) to adjust for increases in processing cost and reduction in revenue due to 1 percent decrease in carcass lean. On the other hand, an increase in the cash-wholesale market price ratio is necessary to reward producers, when the lean percent in carcasses is increased. Given a fixed slaughter cost, the high lean percent carcasses may result in relatively high revenue compared to medium lean percent carcasses. The wholesale cutout values adjusted by Table III-2 may under-estimate the true value of pork at the wholesale level. The ratio for a carcass with 52 percent lean could be adjusted upward by a small percentage (say 0.01 above the base ratio of 0.72, resulting in a ratio of 0.73) to reflect the increase in revenue due to 1 percent increase in carcass lean.

As the relationships between cash hog and wholesale pork cutout markets can be described by α, changes in α in response to changes in carcass lean percent could affect the net prices producers receive. The base price of carcass merit- pricing program for live hogs as shown by equation (3-5) is now

$$P_b = \frac{\alpha_{0.51}}{1.35} \times (0.51 \times \mathrm{CLP}), \qquad (3\text{-}8)$$

after taking slaughter cost, processing cost, or packer preference into account to determine α values.

After taking slaughter cost, processing costs, the opportunity cost of revenue loss, or packer preference into account, the discount rate applied to hogs with 50 percent of lean meat in carcass, $U_1(0.50, \alpha)$, by equation (3-6) is

$$U_1(0.50, \alpha) = \frac{\alpha_{0.50}}{1.35} \times (0.50 \times CLP) / \frac{\alpha_{0.51}}{1.35} \times (0.51 \times CLP)$$

$$= \frac{\alpha_{0.50}}{\alpha_{0.51}} \times \frac{0.50}{0.51}$$

$$= \frac{0.67}{0.72} \times \frac{0.50}{0.51} \tag{3-9}$$

$$= 0.91$$

Detailed ratio values adjusted by the carcass lean percent and the associated net premium/discount rates are shown on Table III-3.

Table III-3. The Calculated Premium/Discount Schedule for Various Carcass Lean Percent

Lean Percent	α	Premium/Discount Rate
0.63	0.72	1.24
0.62	0.72	1.22
0.61	0.72	1.20
0.60	0.72	1.18
0.59	0.72	1.16
0.58	0.72	1.14
0.57	0.72	1.12
0.56	0.72	1.10
0.55	0.72	1.08
0.54	0.72	1.06
0.53	0.72	1.04
0.52	0.72	1.02
0.51	0.72	1.00
0.50	0.69	0.94
0.49	0.66	0.88
0.48	0.63	0.82
0.47	0.60	0.77
0.46	0.57	0.71
0.45	0.54	0.66
0.44	0.51	0.61
0.43	0.48	0.56
0.42	0.45	0.51
0.41	0.42	0.47
0.40	0.39	0.42

The carcass merit-pricing program allows for different returns per unit weight of hog for different quality of hogs. Using Table III-3 to run a regression with premium or discount rates, U_1, as the dependent variable, and fat free lean fraction in carcass weight (LP) as the independent variables, the relationship between premium/discount rates and lean percent in carcass can be estimated by SAS PROC REG as follows.

$$U_1 = EXP(-8.70976 + 29.29888 \times LP - 24.13943 \times LP^2) \qquad R^2 = 0.99 \qquad (3\text{-}10)$$

As the fat free lean fraction in carcass weight increases, U_1 becomes larger.

Table III-4. A Schedule of Premium and Discount for Various Live Weights

FBW (kg)	Premium/Discount Rate
85	0.88
94	0.91
102	1.00
112	1.02
126	1.02
137	0.94

Source: Swine Contract Library (http://scl.gipsa.usda.gov/).

The carcass weight-pricing program allows packers to assign premium (discount) on the prices of pigs with desired (undesired) final body weight. The returns producers receive (dollar per kg) would be different for different final body weight of hogs. A comparison between Table3-1 and Table III-4 shows that for hogs of 51 percent lean in carcass, on which zero discount rates were applied by the quality-merit program, those with final body weight around 120 kg receive 2 percent premium totally. It demonstrates that packers may prefer hogs with size of 120 kg, and have dis-preference against those with under or over- final body weight. Using Table III-4 to run a regression with premium or discount rates, U_w, as the dependent variable, and final body weight (FBW) as the independent variables, the relationship between premium/discount rates and final body weight can be estimated as follows.

$$U_w = -1.21112 + 0.03852 \times FBW - 0.00016607 \times FBW^2 \qquad R^2 = 0.91 \qquad (3\text{-}11)$$

The regression was fitted by a quadratic functional form. Premium/discount rates on final body weight increase as final body weight increases, before the peak is reached.

The Profit Maximization Problem

Suppose a typical hog feeding operator with fixed facility and equipment capacity wishes to apply decision analysis on determining optimal values of some control management variables with respect to the operation's production goal. The goal was assumed to be maximizing profit per pig from an infinite continuous production series. The control management variables were assumed to include environmental factors and feed inputs. Temperature and genotype are two main environmental factors affecting growth (NRC, 1998). When the environmental factors were well controlled, the pig growth process was principally regulated by the nutrient content of the diet offered (Fawcett et al., 1973; 1978). Because of their direct affects on the nutritional quality of the diet, feed inputs are the major determinants of growth after than temperature and genotype. As the nutritional contents of feed ingredients can be identified, the manipulation of the feed composition of the diet on a daily basis is an available and necessary method for regulating growth, output, and profitability.

The biological growth functions estimated by the NRC that predict the growth rate of the hog with specific genetic characteristics can be manipulated by varying the nutritional content of diets. The empirical nutrition-growth relationships which were used in the simulation model in this chapter were described previously in Chapter II. Furthermore, the simulation model established in Chapter II was used as the basis for the problem of economic optimization.

In the simulation model, the pig's protein growth rate in response to nutrient intake is negatively related to body weight and nonlinear in nature over time. The goal of profit maximization for continuous feed operation requires economic optimality that was attained over a series of feeding periods. This incurs a dynamic decision problem of diet composition because the response of growth rate to feed intake changes as the weight and age of the hogs change. Therefore, in the profit maximization problem, a complex dynamic simulation model is required in order to determine the optimal diet compositions over time with the estimated nutrition-growth relationship.

Consider a pig feeding operation where the grower seeks to maximize profit per animal under a carcass merit pricing scheme from a continuous feeding program. The objective function consists of two major components, gross revenue and feed cost, and is stated as

$$Z = \Omega \times Pv\left[R(FBW, LP) - C(\Theta) - C_f\right],$$

where z is the discounted profit obtained on the marketing day, T; Pv is the present value operator; FBW is the final body weight; LP is the lean percent in carcass; $R(\cdot)$ is gross revenue from hog production; $C(\cdot)$ is the variable cost; C_f is the fixed cost; and Θ is the sequence of feed intake over the feeding period, which is dependent on the desired growth path. That is

$$\Theta = \{ FI_t \}, \qquad t = 1,\ldots\ldots,T \text{ ; and}$$

Ω is the approximate capital recovery factor;

$$\Omega = (1+d)^T \big/ \left[(1+d)^T - 1\right],$$

in which d is the interest rate per day.

The present value of gross revenue, $Pv[R(\cdot)]$, is the discounted return from a finished pig at the marketing day, T; i.e.

$$Pv[R(\cdot)] = R(\cdot)/(1+d)^{T\text{-}1}.$$

R is the return from selling the finished pig at the marketing day. R can be calculated by multiplying the net price received for the pig by the pig's live-weight in kilograms. Since the net price received for the pig in the carcass weight and merit-pricing system is a function of final body weight and hog quality, R is also dependent on the hog's final body weight and quality; i.e.

$$R(FBW, LP) = P_b \times U(FBW, LP) \times FBW$$

The cost structure of pig producing operations like any other business consists of fixed cost, C_f, and variable cost, $C(\cdot)$. Shorter feeding periods may have relatively high gains from high lean percent carcasses to feed cost, but there is also a need to replace the herd more frequently, incurring higher initial costs associated with more feeder pigs needed and cleaning fee. Therefore, the fixed costs, such as the initial cost of feeder pigs and cost associated with cleaning pens, should be included in the profit maximization problem. In this study the cleaning fee was ignored. Only feeder pig's cost was included in the model. The discussion on fixed cost will focus on the costs of feeder pigs.

The mathematical programming model must be capable of selecting the most profitable growth path out of the feasible growth rates, and selecting the best mix of feeds to meet the daily nutritional requirements of pigs associated with that growth sequence. Lowering the growth at any day leads to a relative reduction in amino acid and mineral requirements for that day. On the other hand, significant increases in these requirements are necessary to support faster growth. Information on nutritional relationships was obtained from the *Nutrient Requirements of Swine* (NRC, 1998). The requirements of essential amino acids are the sum of those for maintenance, and the gains of body protein. The NRC also provided the amino acid composition of various feed ingredients and their phosphorus and mineral content. The feedstuff composition tables in the *Nutrient Requirements of Swine* (NRC, 1998) were used with the nutrient requirements generated by the growth models to formulate profit-maximizing diets. Diets were formulated on a true digestible amino acid and bio-available minerals (phosphorus and calcium) basis. The true digestible amino acid values for feedstuffs were used in the calculations.

The variable cost is mainly the cost of purchasing feed ingredients. Let $\mathrm{Pv}[\mathrm{C}(\Theta)]$ be the present value of a sequence of daily feed costs for t=1,…,T.

$$\mathrm{Pv}[\mathrm{C}(\Theta)] = \sum_{1}^{T} \mathrm{C}_t/(1+\mathrm{d})^{T-1} ,$$

where C_t is the daily cost of feed ingredients.

Individual grains vary in their essential amino acid and mineral contents. A diverse set of alternative feed ingredients available to the decision maker will increase the nutritional value of diets, and match the profiles of required amino acid and minerals regulated by the growth-nutrient constraints in the profit maximization model at lower cost. Corn, grain sorghum, barley, oats, and wheat were included in the model as the primary energy-supplying ingredients in diets. These cereal grains are severely deficient in several essential amino acids. Soybean meal was regarded as the source of amino acids to formulate the diet, but it also has a deficit in some essential amino acids. Crystalline amino acids, L-tryptophan, DL-methionine, L-lysine, L-threonine were included in the model as the supplemental protein sources. Other mineral sources, dicalcium phosphate, and limestone calcium were also assumed available in the model. In the profit maximization model, as the relative prices of pork or feed ingredients change, adjustments in both feed quantity and diet composition needed to support the desired growth rate must be computed to be economically efficient. A complex system of mathematical programming models in which a linear programming model was included to calculate dynamic least-cost rations was used to determine the optimal growth pattern, subject to the nutritional requirements. Ingredients were selected based on their prices and nutritional quality.

The constrained profit maximization problem with daily adjustment on nutrient requirements for the growing to finishing pig feeding operator is as follows:

$$\max_{T,\, y_{jt},\, BW_t} \quad Z = \Psi \times [(Pb \times U \times FBW)/(1+d)^{T-1} - \sum_{1}^{T} C_t/(1+d)^{T-1} - C_f] \qquad (3\text{-}1)$$

capital recovery factor × (pork basis price × carcass merit system index × final body weight/discount factor less total discounted feed costs less fixed cost)

subject to

$$\sum_{1}^{J} E_j \times Y_{jt} \geq DEI_t \tag{3-I1}$$

(The DE content in the rations)

$$1250 + 188 \times BW_t - 1.4 \times BW_t^2 + 0.0044 \times BW_t^3 \geq DEI_t \tag{3-I2}$$

(The upper bound of DE intake)

$$110 \times BW_t^{0.7} \leq DEI_t \tag{3-I3}$$

(The lower bound of DE intake)

$$\sum_{1}^{J} A(i,j) \times B(i,j) \times Y_{jt} \geq 0.036 \times BW_t^{0.7} \times AAm(i) + 0.12 \times WBPG_t \times AAp(i) \tag{3-I4}$$

(The amino acid content in the ration must be at least equal to what is required)

$$\begin{aligned}\sum_{1}^{J} O(j) \times H(j) \times Y_{jt} \geq {} & (EXP(-0.0557 - 0.416 \times \ln BW_t + 0.005 \times \ln BW_t^2)/100) \times \\ & (1250 + 188 \times BW_t - 1.4 \times BW_t^2 + 0.0044 \times BW_t^3)/3.4\end{aligned} \tag{3-I5}$$

(The phosphorus content in the rations must be at least equal to what is required)

$$\begin{aligned}\sum_{1}^{J} CA(j) \times Y_{jt} \geq {} & (EXP(-0.0658 - 0.1023 \times \ln BW_t - 0.0185 \times \ln BW_t^2)/100) \times \\ & (1250 + 188 \times BW_t - 1.4 \times BW_t^2 + 0.0044 \times BW_t^3)/3.4\end{aligned} \tag{3-I6}$$

(The calcium content in the rations must be at least equal to what is required)

$$\sum_{1}^{J} O(j) \times H(j) \times Y_{jt} / \sum_{1}^{J} CA(j) \times Y_{jt} = 1.9 \tag{3-I7}$$

(The ideal ratio of phosphorus to calcium in the ration)

$$C_t = \sum_{1}^{J} P_j \times Y_{jt} \tag{3-I8}$$

(The feed cost)

$$\begin{aligned}WBPG_t = {} & (17.5 \times e^{-0.0192BW_t} + 16.25) \times (MPAR/125) \times (1 + 0.015 \times (20 - T)) \times \\ & (DEI_t - 0.55 \times 110 \times BW_t^{0.75})\end{aligned} \tag{3-II1}$$

(The whole body protein generating equation)

$$PTG_t(g) = WBPG_t / 0.23 \tag{3-II2}$$

(The daily protein tissue gain)

$$LP = (IFFL + \sum_{1}^{T} 2.55 \times WBPG_t)/(1000 \times FBW/1.35) \tag{3-II3}$$

(The lean percent in the carcass)

$$FSY_t = (0.96 \times DE - 10.6 \times WBPG_t - 106 \times BW^{0.75}) / 12.5 \quad (3\text{-II4})$$

(The daily lipid synthesis from energy intake)

$$FTG_t = FSY_t / 0.9 \quad (3\text{-II5})$$

(The daily fat tissue gain)

$$DBWG_t = (PTG_t + FTG_t) / 0.94 \quad (3\text{-II6})$$

(The daily body weight gain)

$$BW_{t+1} = BW_t + DBWG_t \quad (3\text{-II7})$$

(The body weight accretion equation)

$$FBW = 20 + \sum_1^T DBWG_t \quad (3\text{-II8})$$

(The body weight at the marketing day)

where A(i, j) is the *i*th essential amino acid content in feed ingredient j B(i, j) is the coefficient for true digestibility of amino acid i in feed ingredient j; O(j) is the coefficient for bioavailability of phosphorus in feed ingredient j; H(j) is the phosphorus content in the *j*th feed ingredient; CA(j) is the calcium content in feed ingredient j; P_j is the price of feed ingredient j. AAm(i) and AAp(i) are twelve-element vectors containing the essential amino acid profile for maintenance, and growth, respectively. DEI_t is the digestible energy intake at day t.

Equations (3-I1) to (3-I7) were presented as the constraints regarding nutritional requirements and the associated feeding cost. Equation (3-I1) specifies the total energy values contributed by feed ingredients in the diets. However, under profit maximization growth, controlled (restricted) digestible energy consumption must satisfy equations (3-I2) (the upper limit of daily DE), and (3-I3) (the minimum requirements of daily DE). Equation (3-I4) requires that the sum across ingredient contributions of the *i*th essential amino acid in the diets must be greater than or equal to the requirements for that essential amino acid. Equations (3-I5) and (3-I6) state that the amount of phosphorus and calcium in the diets must be at least equal to what are required. Equation (3-I7) specifies the ideal ratio of phosphorus to calcium in the diets. Equation (3-I8) is the sum of total costs. (3-II1) to (3-II8) are equations regarding pig's growth. The equations describing the growth variables and specifying nutrient requirements were expressed on a daily basis. Detailed description of the growth model and nutritional requirements was presented in Chapter II.

The objective function is to maximize the net return to capital and labor. The profit maximization problem was formulated as follows: given that the hog feeding operator wished to maximize profit per pig and the decisions are made on a daily basis, the objective is to determine the digestible energy of the ration and the number of days the pig is fed before it is sold and replaced with a new feeder pig of 20 kg. Endogenous variables in the model were daily body protein gain (WBPG), daily body weight gain (DBWG), and daily digestible energy intake (DEI). These growth variables were assumed to be functions of state variables such as body weight, lean percent in body weight, and nutrient and digestible energy content of the ration. According to the framework of the profit maximization model, growth was controlled directly by restricted energy intake to achieve profit maximization. Decision choices in the model were made at daily intervals, denoted by d=1, 2, …….T for each batch. This assumption is consistent with Boland et al's (1999) suggestion that there are substantial economic incentives for producers to feed multiple rations, and the highest returns are associated with feeding programs containing most rations. The decision choices to be determined on each day are the energy value of the ration and the most economically efficient composition of feeds. The profit maximization model was built upon the growth path that can be fully described at any day by two growth variables: pig's body weight, and the lean fraction in body weight. The next level of the state variables along the growth path is dependent on current decision made. The decision on the energy and nutrient content of the ration made on the previous day determines the state variables on the current day. In fact, the amounts of body weight or protein gain depends on the decision of the amount and types of feeds fed. The problem is approached with a nonlinear mathematical program with nonlinear constraints. The maximum body weight for which pigs could be fed was set at 120 kg. The biological functions in the NRC simulation model were estimated from experimental data for pigs grown to between 20 and 120 kg, and thus cannot be confidently used to extrapolate results beyond this body weight range. This assumption is also consistent with industry's practice that would prefer hogs with live weight around 120 kg. The price parameters including the prices of feeder pigs and feed ingredients are shown in Table III-5. The average wholesale pork cutout price with 51percent lean for 1990-2003, of $1.3722/lb was used for base price calculations.

The Simulation Result of the Profit Maximizing Problem

The profit-maximizing model was formulated in GAMS 2.5 using the MINOS solver to determine the feed rations needed to support the optimal growth trajectory. Factors assumed to be under management control are the growth levels of the feeder-pig, the length of the feeding period, the energy density of the ration, and the feed composition of the ration.

Table III-5. Prices of Feed Ingredients ($/g) and Feeder Pigs ($/head), and Pork Base Prices ($/kg),

Item	Price	Item	Price
L-tryptophan	0.034	Sorghum	0.00017995
DL-methionine	0.00269	Barley	0.00008809
L-lysine	0.00604	Oats	0.000095
L-threonine	0.00325	Wheat	0.00007964
DicalciumPhosphate	0.00039648	GroundedLimestone	0.00002756
Corn	0.00009348	SBM	0.00020013
Feeder Pig	36.85	Base Price, P_b	0.731858

Source: 1. Heartland Lysine, Inc. (Chicago, IL).
2. Feed Outlook Report, USDA-Economic Research Service.
3. Agricultural Prices Monthly, USDA - National Agricultural Statistics Service.

Because growth rates affect profit from the hog feeding operation, it becomes necessary to select the optimal growth path out of the feasible growth rates. For a given length of feeding period, the nonlinear simulation model was able to determine the optimal growth pattern from a set of feasible growth rates by controlling the energy and nutrient content in the diets. Restricted nutrient and energy supplies involved in the profit maximization problem results in saving in feed. However, pig's body weight was also reduced in response to such restrictions. This reduces the number of pigs that may be produced during the life of the buildings and equipment. Therefore, a proper comparison and selection of the optimal T is also necessary to maximize economic value of carcasses.

The optimal length of feeding period cannot be directly determined by the mathematical programming model formulated in GAMS, in which T is an exogenous parameter with all decision variables being simulated at daily intervals. A line search in which T is varied from 80 to 100 days is used to maximize equation (3-1) was performed by repeated runs of profit maximization model using the MINOS solver. The feeding period T was varied between 80 and 100 days. The estimated economic returns for the standard runs of the model with the various feeding periods, T= 80,……, 100 are shown in Table III-6.

Table III-6. The Results of Profit Maximization Simulation Model

Feeding Period (d)	Profit ($/head)[a]	FBW (kg)	Lean Percent (%)
80	1697.0	106.7	49.7
84	1787.7	112.1	49.6
85	1802.9	113.5	49.6
87	1824.6	116.2	49.5
88	1831.1	117.5	49.5
89*	1844.5	118.9	49.4
90	1833.6	120.0	49.4
91	1819.5	120.0	49.5
95	1772.7	120.0	49.7
100	1717.2	120.0	49.9

[a] The net present value of profit in dollars per pig, with very large rotations of T day feeding period.

The length of feeding period is a crucial factor in determining profitability of hog feeding operations that market pigs on a carcass basis. Figure III-1 demonstrates the effect of T on the optimal constrained infinite period profit given by equation (3-1). The shape of the curve shows the importance of final body weight as well as carcass lean percent in determining profitability of hog feeding operation. The optimal feeding period T^* is at 89 days. Marketing too early would increase discounts for inadequate carcass quality and light carcass weights. From Table III-3, carcasses with 50 percent of lean received a net price 71 percent less than those with 46 percent of lean. For hogs with final body weight under 85 kg, a discount of 88 percent is applied (Table III-4). Net return per head would increase with days fed in this case, which may be attributed to increased carcass weights and a higher lean percent in carcasses. For example, pigs reach the 120 kg body weight at the 90th day in the profit maximization model. Extending the feeding period beyond 90 days generally leads to higher carcass lean percent but lowers profit.

Extending the feeding period beyond 90 days incurs relatively higher feeding cost that cannot be fully recovered by the small increase in revenue under the carcass weight and merit- pricing program used in this study. Nevertheless, a relatively larger reduction in profit was seen for a feeding period longer than 90 days as compared with a feeding period that is shorter than 90 days. It demonstrated that the live weight also played a large role in determining profitability because of its impact on the net price and revenue. Shortening the feeding period leads to reduction in profit, which may be due to relatively low hog body weight. Heavy weight discounts were ineffective for pricing in this study, because the NRC simulation model is valid only for hog body weight ranged from 20 to 120 kg.

Figure III-2 is a graphical representation of growth paths for T = 89, 91, and 100 days. The growth along the entire path corresponding to the optimal feeding period of 89 days was also given in Figure III-2.

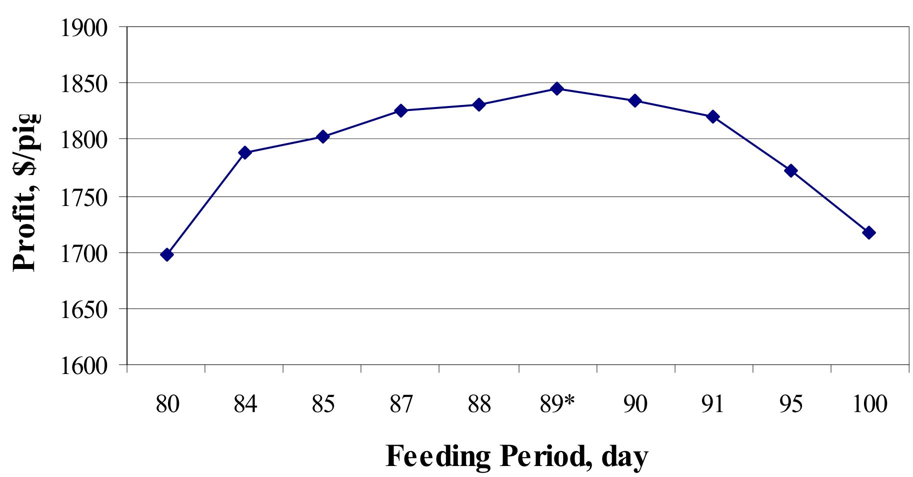

Figure III-1. The Optimal Feeding Period for the Profit Maximization Model

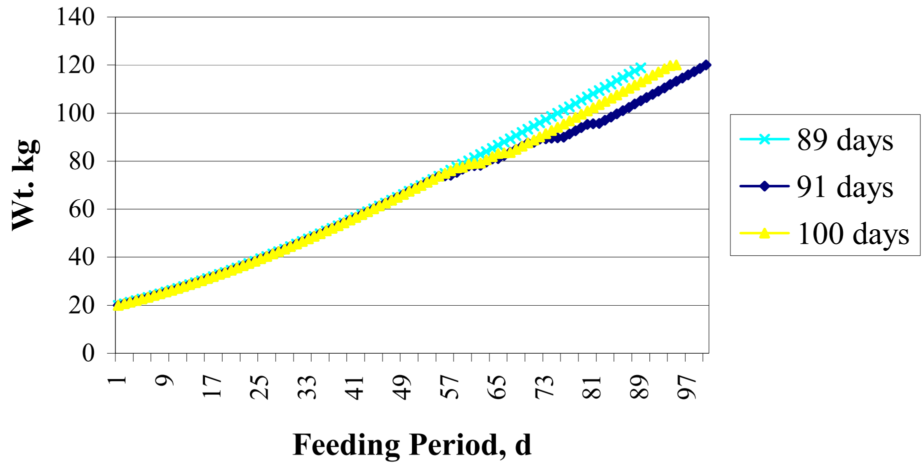

Figure III-2. The Optimal Growth Paths for Various Feeding Periods

As the number of days fed increased, either final body weight or carcass lean percent increased. Table III-6 shows that before pigs reach 120 kg, the final body weight constraint, the marketing weight increased as days fed increased, while the carcass lean percent was little altered. As final body weight constraint of 120 kg was binding, days on feed were generally used to accumulate lean percent in body weight. The curves in Figure III-2 show that the extent to which feeding is restricted also increases with the number of days fed. Carcass lean percent is expected to increase so as to receive premiums for higher carcass quality as days fed increased. Note that restricted feeding for the profit maximization model with carcass weight and merit- pricing program occurs in the latter part of the growth path. This result seems to be consistent with the hypothesis suggested by the National Research Council that younger pigs have greater lean growth efficiency. Profit maximizing operators would maximize pig growth in the early stages of feeding so as to obtain the maximum gain of lean meat at least cost. Under the carcass merit- pricing program in which the premium/discount rates are dependent on the lean percent in carcass, hog feeding operators would then restrict pig growth in the later stage of growth to slow animal body weight gain, and thus increase the lean percent in the carcasses. Figure III-3 shows the carcass fat-free lean growth path corresponding to the optimal feeding period of 89 days.

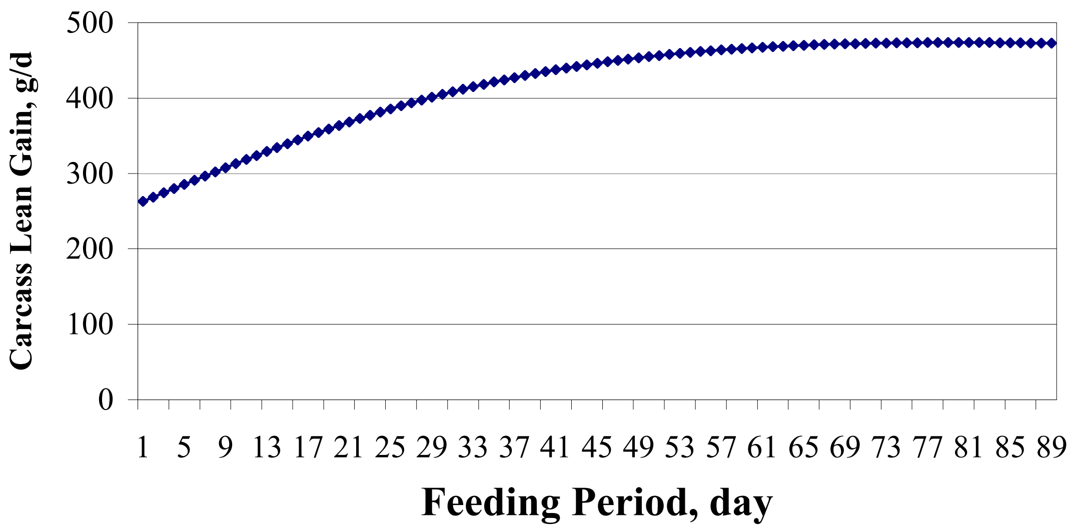

Figure III-3. The Optimal Growth Path for the Feeding Period of 89 Days

Under the assumption that ambient temperature was maintained at 20^0C, the optimal levels of performance for pigs with high lean growth rate were simulated for a feeding period of 89 days. Appendix Table A-3 gives detailed optimal levels of performance for pigs with high lean growth rate in an environment with the ambient temperature of 20^0C. The optimal weight sequence can be seen graphically in Figure III-2. The present value of the revenue stream to infinity is $4290.4, and the present value of the feeding cost stream to infinity including the cost of procuring feeder pigs is $2446.0, which implies a present value of the profit stream to infinity (without including waste management cost) is $1844. At a rate of interest of 0.0274 percent per day, the one batch profit per pig (without considering waste management cost) is \$44.4 by the end of every 89 days.

The associated waste management cost for the profit maximizing growth was estimated for the representative swine feeding operation with the Decision Support System (Stoecker et al., 1998). The representative swine operation was assumed located in the district of Panhandle, Oklahoma, and with 4, 000 pig capacity. Under the P constraint, the manure management system of fully slated floor, pull plug, anaerobic lagoon, and irrigation with a traveling gun performed the best in terms of cost per animal space for the representative farm analyzed (Carreira et al., 2000). The necessary capacity of the waste management system and its related cost were presented in the Table III-7. The manure management cost (dollars per pig) for the fifteen year period was \$231. An anaerobic lagoon of 2.0×10^6 cuft was needed for the swine feeding operation seeking maximizing the profit from pork production with animal capacity of 4, 000 pigs. It needs 1437 acres of dryland sorghum for the land application of all generated manure.

Appendix Table A-4 gives summaries of nutrient requirements for profit maximization levels of performance for pigs with high lean growth rate ignoring the effects of environment temperature (assuming the ambient temperature is 20^0C). LysinT is the total lysine requirement, LysinM is the lysine requirement for maintenance, and LysinG is the lysine requirement for growth, expressed as grams per day.

Table III-7. The waste management components and cost for the profit-maximizing swine operation with animal capacity of 4,000 pigs under a P restriction.

Item\Capacity	Value
Final Wt, kg	118.9
Profit, $/pig 89 days[a]	44.4
Gross Revenue, $/pig 89 days	103.3
Feed Cost, $/pig 89 days	58.9
Waste Cost, $/pig 15yrs[b]	231.0
CLG[c], $/ 15yrs	131747.5
APC[d], $/ 15yrs	223299.7
HOC[e], $/ 15yrs	0
Application Acre	
Sorghum	1436.6
Wheat	0
Lagoon Size, cuft	2.0×10^6
Manure App, cuft	2.0×10^6
Manure Haul, cuft	0
NCLG[f], lbs/cuft	0.019
PCLG[g], lbs/cuft	0.013

[a] The profit refers to the profit per pig (not including waste handling cost) in dollars for a single feeding period of 89 days.
[b] The waste cost refers to the waste management cost of 15 year period in dollars per pig.
[C] The total cost of anaerobic lagoon (CLG), which includes initial construction, land, and lifetime maintenance and repair cost.
[d] The total cost of application with a traveling gun for the continuing land application programs.
[e] The total cost of hauling excess manure off the farm.
[f] N content in lagoon liquid.
[g] P content in lagoon liquid.

Results from the profit maximization simulation model show that profits from hog production are maximized by feeding ration with steadily increasing digestible energy and lysine content during 89 days of feeding. The optimal plan consisted of feeding pigs high DE rations, in which DE content increases from 3905 kcal to 11538 kcal during the feeding period of 89 days. Weight gains therefore steadily increased until the final day of feeding. Because older pigs tend to have decreasing lean growth efficiency, the optimal level of lysine contained in the final rations was increasing in the early period and then declining in the latter period. The optimal diet included increasing level of lysine in the early weeks followed by a decrease in lysine levels in the last five days. This result is consistent with the National Research Council recommendations for feeding a increasing DE and lysine diet in the early stages of high lean growth followed by stable amounts of DE and lysine in the stages of slower lean growth.

In addition to the growth trajectory and nutritional estimation, feed composition also had to be included in the model as a major decision variable. The profit-maximizing simulation model that was capable of accounting for dynamic changes in the nutritional requirements can also be used to compute optimal rations along the optimal growth path. None of the synthetic amino acids, L-tryptophan, DL-methionine, L-lysine, L-threonine were included in the optimal diets for pigs with high-medium lean growth rate. Among the energy-supplying ingredients, only wheat was included in the optimal rations. This result is consistent with the recommendation made by the Oklahoma Cooperative Extension Service that wheat contains high protein and lysine, and is an excellent swine feed when it is competitively priced (Fact Sheet-3500, Oklahoma Cooperative Extension Service). However, a certain amount of soybean meal (SBM) is also included in diets as a protein supplement to ensure that the lysine and other essential amino acid requirements for optimal growth are met. Ground limestone (LimstonG) was also included in the diets to meet phosphorus and calcium requirements. Appendix Table A-5 shows the amount and percentage of each ingredient of the optimal daily ration.

Discussion

The profit maximization model assumes that hogs are priced in terms of lean meat content in carcasses. The *Nutrient requirements of Swine*, however, does not specify the nutrient requirements in terms of the nutrients required to produce daily body weight gains of specified composition. In the NRC simulation model, the protein content is expressed in terms of the total body weight. As the lean meat content in carcasses is used as a measure of hog quality by the industry, the protein content is not immediately meaningful to market participants, even if expressed in terms of carcass weight. However, protein accretion is closely related to the gains of carcass fat free lean meat; the carcass fat free lean meat rate can be transformed from protein accretion rate using equation (2-5). The ratio of carcass weight to animal body weight provided by the Swine Contract Library makes allowances for calculation of carcass weight given a final body weight. The modified NRC simulation model thus can be used to determine the optimal feeding policy for the specified final body weight and carcass composition. Although the profit maximization problem uses the pig growth model constructed by the NRC *Nutrient requirements of Swine*, the method can be used with any pig growth model in which the development of the animal can be expressed in terms of two variables, body weight and carcass lean meat content, provided that the nutritional requirements for producing specified changes in these variables can be accounted for. One example is the pig growth model of Fawcett et al.

An introduction may help compare the growth model of Fawcett et al. (1978) with the growth model from NRC *Swine Nutrition Guides*. In the model of Fawcett et al. (1978), the daily body weight gain of the growing pig is separated into fat free and fatty tissue components expressed in terms of protein retention, and lipid retention, respectively. Although many nutrients, such as energy, protein, minerals, vitamins and water, are required for their specific functions in producing weight gains of specified body composition, the principal nutrients in pig growth are energy and protein (Fawcett et al., 1978). Fawcett et al. (1978) assumed that energy is required to maintain body functions and grow new tissues, while body protein is mainly produced by conversion of digestible protein in diets. In the model of Fawcett et al., the maximum rate of protein retention and the minimum value of the ratio of lipid to protein retention must be specified and will depend on pig's generic potential. For a specified genotype of pig it is assumed that genetic potential affects the maximum rate of protein accretion, and the daily protein retention must not exceed that maximum value. The ratio of lipid retention to protein retention in daily body weight gain was supposed to exceed a minimum value that was also assumed dependent on the genetic potential. The genetic potential is also a major factor that is influencing the efficiency of conversion of feed intake in a healthy pig, which in turn affects the coefficients in energy requirement equations in the pig growth model of Fawcett et al.

In the model of Fawcett et al. (1978), total daily protein synthesis is composed of new protein synthesis plus resynthesis of part of the protein which has been broken down. The daily new protein synthesis is assumed dependent on both the quantity and quality of the dietary crude protein intake. The quality of dietary protein is defined in terms of its digestibility and relative amino acid profile to preferred amino acid profile of the animal growth. The amino acid profile of a feed is the content of each amino acid in the feed, and expressed as a percentage of feed protein mass. Since the amino acid profile of the feed does not necessarily match the preferred amino acid profile of the animal, protein quality is determined by the most limiting essential amino acid in the feed when the amino acid profile of the feed is compared with the preferred amino acid profile of the animal. Fawcett et al. further define chemical value as the minimum value obtained when the concentration of each essential amino acid in the feed is divided by the corresponding value in the preferred profile. If a pig is fed a ration of digestible crude protein, the daily new protein synthesis is, therefore, the digestible protein content of the ration time its chemical value. In the pig growth model of Fawcett et al. (1978), the new protein synthesis is assumed to be a ratio of protein retention, with the ratio of new protein to total protein synthesis being dependent on the maturity of the animal.

The pig growth model developed by Whittemore and Fawcett had been used by Fawcett et al. (1978) to determine the least cost rations to produce a particular daily body weight gains of specified composition using the method of linear programming. A linear programming model in which body weight gain is supposed to consist of fat free and fatty tissue components was used to determine the least cost rations involved in a given increases in the body weight and the protein content. The associated daily protein retention with the required values of daily body weight gain can be calculated from the body weight gain composition equation by choosing appropriate values of the ratios.

Since it is final body weight and carcass composition that determine the profit from a pig feeding operation, using the least cost rations for a particular body weight gains of specified body composition obtained from the ration formulation model of Fawcett et al (1978) throughout the fattening period may lose the overall efficiency. An optimal feeding policy should involve feeding least cost rations throughout the fattening period in such a way that the total production cost is minimized. As the production cost and the weight and carcass composition of the pigs produced are affected by the sequences of rations, the feeding policy should formulate the sequence of rations to achieve the overall efficiency of the hog feeding operation. Glen (1983) determined the sequence of least cost rations to produce pigs of the required body weight and carcass composition at minimum cost by using dynamic programming (D.P.) model. In Glen's approach, a dynamic programming model in which state variables were defined in terms of body weight and protein content was used to determine the cost minimization/profit maximization values of the state variables. Final body weight and carcass composition are choice variables, and are dependent on marketing opportunities. An L.P model was then used to determine the least cost rations to produce body weight gains of specified body composition in a t day period. To determine the overall optimal feeding policy, all the least cost rations must be calculated for each of the possible combinations of the states at the start and end of a t day period, with daily increments in body weight and the protein content being equal over the period.

The approach involves using dynamic programming (D.P.) to determine the sequence of least cost rations has been used in a similar context for broiler production by Kennedy et al. (1976), for determining for each decision stage whether to sell broilers given a set of estimated prices. The model of Kennedy et al. (1976) is similar to the method developed by Glen (1983) for the operation producing pigs of the required body weight and carcass composition at minimum cost, although in the case of broiler production, the carcass composition was not taken into account. Generally two methods were applicable to solving the dynamic programming model of broiler production (Kennedy et al., 1976). Given a guessed return from pursuing the optimal policy at the first period, one method of successive approximations, known as value iteration, could be used to find the decision variables to be made for all body weights at all stages, and the return stream as a whole. The new estimate of return from pursuing the optimal policy at the first period included in the whole return stream estimated would then result in another estimated value of decision variables. If this process were repeated enough times, the estimated return to infinity would converge to a particular value, and decision variables would be determined. However, a solution obtained from another successive approximation method, known as policy iteration, is more rapid and precise. A guess at the decision variables implies a corresponding estimate of return from pursuing the optimal policy at the first period, which in turn could be used to estimate the values of decision variables. The optimal decision levels were found, when converging to a particular value.

Dynamic programming is a good solution method for the multi-stage problem of animal production, given that the composition of the diet are permitted to change during the growing period, which suggests that the decision problem is of a larger dimension. However, the use of DP rather than a simulation suggested that some of the flexibility and precision inherent in a simulation model might be lost. The numerical solution method implied that the discrete values of the state and decision variables must be within some types of ranges that had to be specified for the DP problem. In the D.P. model, the body weight gains over periods were chosen to be integral multiples of the assumed value, which is constrained to be less than the maximum body weight gain of a pig over the periods. The ranges of state variables of pig production at the beginning of any period, body weight and carcass composition were therefore covered by a limited number of weights and protein percent spaced at equal intervals throughout. Because the body weight growth is a function of the digestible energy content of the ration, the weight gain range implies that the corresponding decision variables, digestible energy content of rations, is also having the minimum and maximum limits. The possible range of body weights at the beginning of any period can therefore be found by calculating the minimum and maximum weight gains, assuming the rations of minimum and maximum DE respectively are fed. Since the state and decision variables of the animal production, expressed in terms of body weight of specific composition and DE content, must be in discrete units within the minimum and maximum limits, the DP model may only provide approximate solutions to determine the overall optimizing feeding policy.

The profit maximization models of pig growth have been developed on the GAMS programs using a general microcomputer. For this reason the program is also suitable for use by individual hog producers beyond the initial purpose of developing the model as a research tool.

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CHAPTER IV

THE MODIFIED NRC SIMULATION MODEL

A suitable simulation model for the swine profit maximization problem must be capable of predicting pig performance over a wide range of nitrogen and phosphorus ratios, and feed ingredients. The validity of the simulation model in the case of reduced crude protein and phosphorus content in diets is of particular interest. In this chapter, the dynamic system simulation model adopted from the National Research Council (Nutrient Requirements of Swine, 1998) will be validated against results from a series of low protein and phosphorus feeding trials conducted at Oklahoma State University (Carter et al., 1999; 2000; 2001; and 2003). The predictability of the growth variables of the NRC simulation model across various dietary regimes will be analyzed as a randomized complete block using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). The null hypothesis that the predicted values of NRC model are not different from the experimental ones will be tested. Based on hypothesis test results, further re-estimation will be conducted with the experimental data below to evaluate and enhance the predictability of the simulation model across different dietary regimes.

Review of Swine Feeding Trials

Ten experiments were conducted by Carter *et al*. (1999, 2000, 2001, and 2003) at Oklahoma State University to investigate the effect of crude protein (CP) or phosphorus

(P) content in diets during the growing phase on growth performance, nitrogen and phosphorus excretion, and carcass traits in pigs. The goals of diet formulation and feeding strategy in these experiments are all to measure the effect of the forms and the amount of dietary nitrogen and phosphorus on animal performance. In each experiment, barrows within a litter were allotted randomly to different dietary treatments. Each experiment contains three to four dietary treatments. Pigs were housed individually in an environmentally controlled room in metabolism chambers. Metabolism chambers allowed the separate, but total collection of urine, feces, and refused feed. Each chamber contained a stainless steel feeder, a nipple water nozzle, galvanized grated flooring, feces and urine separation screen, and a urine collection pan. The room temperature was maintained at 24^0 Celsius to achieve optimal animal performance. Trace minerals and vitamins for all diets were provided in the amount calculated to meet or exceed the NRC (1998) requirements. Mineral supplements were added to diets to provide a constant ratio of calcium to available P (1.9:1) across the all treatments. Reagent grade potassium chloride, potassium bicarbonate, and sodium carbonate were added as needed to equalize electrolyte balance across the treatments. Energy content was also equalized across the treatments in each experiment. Generally, pigs were fed the dietary treatments for an adjustment period followed by a collection period. During the collection period, urine, feces, refused feed, and feed consumption data were collected daily. Pigs and feeders were weighted on the beginning and final day of the collection period to monitor daily body weight gain, nitrogen retention, phosphorus retention, and feed intake. Pigs were allowed ad labium access to feed and water in all experiments. Table IV-1 gives the data sources, number of pigs, genotypes, average initial body weights in kg, and the length of adaptation and collection periods for each experiment (Carter *et al*., 1999; 2000; 2001; 2003).

Table IV-1. Summary of Swine Feeding Trials

Expts	Reference	Set/littermates	Pig	Initial wt[b]	Adjust.[c], d	Collect.[d], d
Exp 1	Senne exp1[g]	6/4[a]	YH[e]	17.3 kg	14	5
Exp 2	Senne exp2	6/4	YH	34.0 kg	7	5
Exp 3	Shriver exp1	6/4	PIC	36.3 kg	9	5
Exp 4	Senne exp3	6/4	YH	31.0 kg	7	5
Exp 5	Senne exp4	6/4	YH	30.0 kg	7	5
Exp 6	Fent exp3	6/4	Y, YL, YH	27.5 kg	7	5
Exp 7	Fent exp2	8/3	Y, YL	25.6 kg	7	5
Exp 8	Fent exp4	12/3	Y	25.9 kg	5	4
Exp 9	Petty Exp5	5/4	Y, YH	31.3 kg	3	5
Exp 10	Park exp1	42[f]	YH	19.9 kg	9	5

[a] set number / littermate number of pigs used in the experiments.
[b] Initial wt = the initial animal body weight at the beginning day of the experiment, in kg.
[c] Adjust.= the adjustment period in days that allows pigs adapting to chambers and experimental diets.
[d] Collect.= the collection period in days, in which urine, feces, and refused feed were collected daily.
[e] YH=Yorkshire × Hampshire. PIC=PIC, Hennessey, OK. Y=Yorkshire. YL= Yorkshire × Landrace. [f] 42 barrows were used in the exp 10.
[g] refer to the theses (Senne, 2001; Shriver, 2000; Fent, 2001; Petty, 2000; Park, 2003).

The chemical analysis procedure according to the information published in Carter *et al*.'s research (1999; 2000; 2001; 2003) can be described as follows. Prior to the beginning of the collection period on day 0, all excess feed, feces, and urine were removed from the chambers. Fecal output, and urine volume were collected, measured, and recorded on a daily basis, with feces and urine being frozen in a cooler maintained at -4^0 Celsius for analysis. Before the collection period chromic oxide was included at 0.15 percent of the diet as a marker for the beginning and end of the collection period. Fecal and urine collection began when feces first exhibited signs of altered color, and stopped when feces turned back to a normal appearance. The feces were freeze dried for 7 days to determine dry matter content prior to analyses for total nitrogen and phosphorus. At the end of the collection period the feces were removed from the collection bag labeled with the appropriate pen number and date and placed in a large container for a sub-sample to be taken. Feces from each day of the collection period were thoroughly mixed together for a representative sub-sample. The sub-sample was then ground and placed in another bag labeled with the appropriate pen number to later be analyzed.

Urine samples were handled in a similar manner in the experiments (Carter et al., 1999; 2000; 2001; 2003). Daily frozen urine samples were thawed and then poured into a container to be stirred thoroughly for an accurate sub-sample. During the urine collection process 15 ml of concentrated hydrochloric acid was added to the urine collection pans to prohibit nitrogen volatilization. Urine samples were composited for each pig by combining one percent of each day's urine volume and the composited sample was analyzed for total nitrogen, urea nitrogen, ammonia nitrogen, and P. Three representative sub-samples of feces and urine were taken for each pen, with the average of the three being reported. Feed sample from each dietary treatment was analyzed for dry matter (DM), energy concentrations crude protein (CP), amino acids, and nitrogen (N) and phosphorus (P) similar to that performed for the feces. Feed, feces, and urine were analyzed for nitrogen content by Kjeldahl methodology after the end of the collection period. The phosphorus content in feces and urine were determined by colorimetric analysis (Sigma, Proc. 670). Total nitrogen and phosphorus excretions were calculated by adding the amount of the nutrients excreted in the urine and feces. N and P balances were calculated by subtracting nutrient excretion from nutrient intake (Carter *et al*., 1999; 2000; 2001; 2003).

Experiment 1. The purpose of this experiment was to determine performance, and nutrient and phosphorus excretion from pigs fed four diets with approximately 3,900 kcal digestible energy per kg when CP varied from 12 percent to 19 percent, and total P content varied from 0.33 percent to 0.61 percent. Crystalline amino acids were added on an ideal basis to maintain a constant amino acid balance. All diets were to contain 0.82 percent digestible lysine and 0.31 percent available P. Corn and cornstarch (CS) and soybean meal and casein were used as sources of energy and amino acids respectively to formulate practical diets. Diet 1, which had 12.5 percent CP and 0.33 percent total P with supplemented essential amino acids, was formulated to result in minimal nitrogen and P excretion. In Diet 2, CP was increased to 17.1 percent by replacing a portion of the cornstarch with corn. Diet 3, in which CP was increased to 21.8 percent, was formulated with soybean meal replacing casein. Diet 4 that had 19.6 percent CP and 0.61 percent total P was formulated with corn and soybean meal. Soybean oil was added to make all diets isocaloric.

Experiment 2. Diets in this experiment (Table IV-3) were formulated using cornstarch and one of four soybean fractions with lower CP values than in the experiment 1 to determine the effects of different soy sources on nitrogen and phosphorus excretion. The crude protein levels of the diets varied from 12 to 14 percent. Diet 1 (14.1 percent CP) contained soybean meal (SBM) as the single source of dietary protein. Including a high amount of fermentable fiber in diets can greatly reduce nitrogen excreted in urine, and thereby reduce the ammonia content in pig manure and ammonia emission (Canh et al., 1999; Zervas, 2002). In diet 2, soybean hulls were added and replaced a portion of soybean meal in diet 1 (SBMH). Soy protein concentrate (SPC) and soy protein isolate

(SPI) was the dietary protein source of Diet 3 (13.3 percent CP) and Diet 4 (14.3 percent CP), respectively. Crystalline methionine and threonine were added on an ideal basis to maintain a constant amino acid balance. Digestible lysine was maintained constant at 0.75 percent in all diets. Calcium carbonate and monosodium phosphate were utilized as sources of calcium and P.

Table IV-2. The Nutrient Content and Ingredient Composition of the Diets in Experiment 1 (on an as-fed basis)

		Treatment			
	Req.[d]	Diet 1 CS[b]&Caesin	Diet 2 Corn+CS&Caesin	Diet 3 CS&Caesin+SBM	Diet 4 Corn&SBM
Wt, kg		30.01	28.86	30.33	28.30
Ingredient%					
Cornstarch		79.17	17.90	61.27	--
Casein		11.70	10.21	1.49	--
Corn		--	60.51	--	60.51
SBM-48		--	--	27.78	27.78
Calculated values					
DE, kcal/kg	3399	3973	3830	3943	3800
CP, %		12.5	15.4	18.2	19.6
Digt.Lys[a], %	1.14	0.82	0.82	0.82	0.82
P, %	0.53	0.33	0.45	0.48	0.61
Avail. P, %	0.22	0.31	0.31	0.31	0.31
Analyzed values (Percent)					
CP		13.8	17.1	20.3	21.8
P		0.38	0.45	0.54	0.68

[a] Diets were formulated to contain .82 percent digestible lysine and .31 percent available P. A constant ratio of Ca:available P (1.9:1) was maintained across treatments.
[b] CS refers to cornstarch used in the experiment.
[c] TSAA refers to total sulfur amino acids, which consist of methionine and cystine.
[d] Digestible energy and [True] ileal digestible AA requirements, Table 10-1, NRC (1998).

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 1999. "Effects of Corn and (or) Soybean Meal on Nitrogen and Phosphorus Excretion of Growing Pigs." *Oklahoma Animal Science Research Report*. Pp280-286.

Experiment 3. The excretion of nitrogen was jointly influenced by fiber type, as well as fiber and protein content in diets (Sorensen *et al*., 2003). Diets with a high fermentable fiber content greatly reduced urine nitrogen excreted, and thereby the ammonium content in pig manure and ammonia emission (Canh et al., 1999; Zervas, 2002). The purpose of the Experiment 3 was to determine the effects of fiber additions to low protein, amino acid supplemented diets (Carter *et al*., 2000). Diet 1, the control (18 percent CP) was fortified with corn-soybean meal diet. All other diets have 14 percent CP, but are supplemented with crystalline amino acids to achieve an ideal ratio to digestible lysine. Diet 2 (14 percent CP) was formulated to test the effects on nitrogen excretion and retention, as dietary crude protein reduced by 4 percent units, supplemented with L-lysine HCL, L-threonine, DL-methionine, L-tryptophan, L-isoleucine (LPAA) on an ideal basis. Diet 3 was as Diet 2 plus L-valine and soybean hulls added at 10 percent of the diet (SBH, 11.4 percent CP). Diet 4 as 2 plus L-valine and 10 percent dried beet pulp (DBP, 8.6 percent CP). Soybean hulls or beet pulp were added to diets 3 and 4 at the expense of corn and soybean meal. Calcium carbonate and monosodium P were used as the sources of calcium and P.

Experiment 4. Pigs within each litter were randomly allotted to one of four dietary treatments to determine the effects of reduction in crude protein content of diets with amino acid supplementation and inclusion of different soy products on N retention and excretion. Diet 1 (19.4 percent CP and 0.56 percent total P) that served as the control was fortified corn-soybean meal diet. All other diets were formulated to have 15.4 percent CP but lower total P. Diet 2 (0.53 percent total P) was a low CP, amino acids supplemented diet. Dietary crude protein was reduced by 4 percent units than Diet 1 but was supplemented with L-lysine HCL, L-threonine, DL-methionine, L- threonine, L-tryptophan, L-isoleucine, and L-valine on an ideal basis. Diets 3 and 4 were also low CP supplemented diets with either soybean protein concentrate or soy protein isolate replacing the soybean meal in Diet 2. Diet 3 and Diet 4 contained 0.52 percent and 0.50 percent total P, respectively. All diets were formulated to contain 0.86 percent digestible lysine. Dicalcium phosphate and calcium carbonate were utilized as the sources of P and calcium.

Table IV-3. The Nutrient Content and Ingredient Composition of the Diets in Experiment 2 (on an as-fed basis)

		Treatment[c]			
	Req.[b]	Diet 1 CS&SBM	Diet 2 CS&SBMH	Diet 3 CS&SPC	Diet 4 CS&SPI
Wt, kg		37.83	37.76	35.79	36.09
Ingredient (percent)		65.19	60.38	76.44	79.23
Cornstarch		29.52	28.75	--	--
Soybean meal, 48 %		--	4.11	--	--
Soybean hulls		--	--	19.26	--
SPC		--	--	--	16.29
SPI		65.19	60.38	76.44	79.23
Calculated values					
DE, kcal/kg	3399	3783	3813	3847	3845
Percent CP		14.1	14.1	12.5	14.2
Percent Digestible Lys	1.05	0.75	0.75	0.75	0.75
Percent total P	0.50	0.49	0.48	0.44	0.41
Percent available P	0.20	0.31	0.31	0.31	0.31
Analyzed values					
Percent CP		14.1	13.8	13.3	14.3
Percent total P		0.44	0.51	0.42	0.44

[a] TSAA refers to total sulfur amino acids, which consist of methionine and cystine.
[b] Digestible energy and true ileal digestible AA requirements, Table 10-1, NRC (1998).
[c] Diet 1 contains soybean meal (SBM) as the single source of dietary protein. In Diet 2, soybean hulls were added and replaced a portion of soybean meal in diet 1 (SBMH). Soy protein concentrate (SPC) and soy protein isolate (SPI) was the only soy protein source in respective Diet 3 and Diet 4.

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2000. "Nitrogen and Phosphorus Excretion from Pigs Fed Different Soybean Fractions." *Oklahoma Animal Science Research Report*. Pp129-135.

Table IV-4. The Nutrient Content and Ingredient Composition of the Diets in Experiment 3 (on an as-fed basis)

	Req.[b]	Treatment[c] Diet 1 Corn&SBM	Diet 2 LPAA	Diet 3 Corn&SBMH	Diet 4 Corn&SBMP
Wt, kg		40.60	33.39	39.48	39.73
Ingredients (percent)		71.12	72.22	71.56	71.63
Corn, dent grain		25.94	14.40	14.42	14.41
SBM, dehulled		--	--	10.00	--
Soybean hulls		--	--	--	10.00
Beet pulp		--	10.00	--	--
Cornstarch		1.00	1.00	1.00	1.00
Soybean oil		1.23	1.58	1.55	1.57
Dicalcium phosphate		71.12	72.22	71.56	71.63
Calculated vlaues					
DE[a], kcal/kg	3399	3523	3517	3408	3416
Percent Crude Protein		18.00	14.00	14.00	14.00
Percent Digestible Lys	0.99	0.78	0.82	0.80	0.78

[a]Calculated with the composition of rations and the DE content of feedstuffs (NRC, 1998).
[b]Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[c] Diet 1=fortified corn-soybean meal diet. Diet 2 (LPAA) =Diet 1 with dietary crude protein reduced by 4 percent, and supplemented with synthetic Amino Acids. Diet 3=Diet 2 plus L-valine and soybean hulls (SBH) added at 10 percent of the diet. Diet 4=Diet 2 plus L-valine and dried beet pulp (DBP) added at 10 percent of the diet.

Source: Carter, S.D., A.L. Sutton, B.T. Richert, B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Effects of Adding Fiber Sources to Reduced-Crude Protein, Amino Acid-Supplemented Diets on Nitrogen Excretion, Growth Performance, and Carcass Traits of Finishing Pigs." *Journal of Animal Science*. 81:492-502.

Experiment 5. The purpose of this experiment was to determine the effects of reduction in crude protein content of diets with amino acid supplementation and addition of different protein sources on N and P retention as well as excretion. Diet 1 (19.5 percent CP but only 0.19 percent total P) was formulated with highly digestible cornstarch and casein as sources of carbohydrates and protein. Diet 1 served as the control diet designed to result in minimal P excretion. Diet 2 (15.2 percent and 0.56 percent CP and total P respectively) was a fortified corn-soybean meal diet. Diet 3 (15.2 percent and 0.53 percent CP and total P respectively) is a LPAA diet with dietary crude protein reduced by

4 percent units, and supplemented with L-lysine HCL, L-threonine, DL-methionine, L-tryptophan, L-isoleucine, and L- valine on an ideal basis. Diet 4 with only 11 percent CP and 0.52 percent total P also used soybean protein concentrate (SPC) to replace the soybean meal in the diet. All diets were formulated to contain 0.87 percent digestible lysine. Dicalcium phosphate and calcium carbonate were utilized as the sources of P and calcium (Carter *et al*., 2000).

Table IV-5. The Nutrient Content and Ingredient Composition of the Diets in Experiment 4 (on an as-fed basis)

		Treatment[c]			
	Req.[b]	Diet 1 Corn&SBM	Diet 2 LPAA	Diet 3 Corn&SPC	Diet 4 Corn&SPI
Wt, kg		33.70	33.39	32.21	32.15
Ingredient (percent)					
Corn		67.01	77.90	83.44	86.09
Soybean meal, 48 %		29.00	17.50	--	--
Soy protein concentrate		--	--	12.20	--
Soy protein isolate		--	--	--	8.85
Calculated values					
DE[a], kcal/kg	3,399	3,431	3,391	3,457	3,424
Percent CP		19.40	15.40	15.40	15.40
Percent Digestible Lys	1.04	0.92	0.84	0.84	0.82
Percent phosphorus	0.52	0.56	0.53	0.52	0.50
Analyzed values					
Percent CP		19.40	15.20	14.90	15.20
Percent total P		0.60	0.55	0.54	0.53

[a]Calculated with the composition of rations and the DE content of feedstuffs (NRC, 1998).
[b] Digestible and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[c]Diet 1=fortified corn-soybean meal diet. Diet 2=Diet1 with dietary crude protein reduced by 4 percent, and supplemented with synthetic amino acids. Diet 3 and 4 were as Diet 2 with either soybean protein concentrate (SPC) or soy protein isolate (SPI) completely replacing SBM in Diet 2.

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Nitrogen Balance of Growing Pigs Fed Low Crude Protein, Amino Acid Supplemented Diets with Different Soybean Products." Department of Animal Science, Oklahoma State University.

Table IV-6. The Nutrient Content and Ingredient Composition of the Diets in Experiment 5 (on an as-fed basis)

	Req.[a]	Treatment			
		Diet 1 CS&Casein	Diet 2 Corn&SBM	Diet 3 LPAA	Diet 4 Corn&SPC
Wt, kg		21.09	22.82	23.02	23.98
Ingredient (percent)					
Corn		--	65.19	75.63	80.99
Corn Starch		80.89	--	--	--
Soybean meal, 48 %		--	30.30	18.80	--
Soy protein concentrate		--	--	--	13.50
Casein		12.61	--	--	--
Calculated values					
DE[a], kcal/kg	3399	3651	3415	3359	3423
Percent CP		19.20	15.20	15.20	11.00
Percent Digestible Lys	1.07	0.88	0.96	0.88	0.87
Pecent total P	0.55	0.26	0.56	0.53	0.52
Analyzed values					
Percent CP		19.5	14.7	15.3	11.4
Percent total P		0.19	0.56	0.49	0.47

[a] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Nitrogen Balance of Growing Pigs Fed Low Crude Protein, Amino Acid Supplemented Diets with Different Soybean Products." Department of Animal Science, Oklahoma State University.

Experiment 6 Experiment 6 was initially designed to determine the energy and nitrogen balance of growing pigs fed diets containing four corn grains (designated only as corn A, B, C, and D). Corn varieties A, C, and D were normal varieties while corn B was a high-oil variety. These diets are "low" in crude protein as the CP values vary from 12.4 to 13.2 percent. Pigs were fed one of four diets, each containing one of the four corn grains at 90.48 percent (Carter *et al.*, 2001). While all four diets have only 12 to 13 percent CP, they have been supplemented with synthetic amino acids to meet NRC requirements. Diet 1 contains corn A. Diet 2 contains corn B. Diet 3 contains corn C, and Diet 4 contains corn D. Casein and amino acids were added to the diets to meet or exceed amino acid requirements (casein was included at 5.04 percent of each diet). Limestone and dicalcium phosphate were utilized as sources of calcium and phosphorus. Dry matter, gross energy concentrations, and nitrogen content were determined for the corn grains, as well as the four treatment diets. The analyzed energy and crude protein concentrations for the diets were showed in the Table IV-7.

Table IV-7. The Nutrient Content and Ingredient Composition of the Diets in Experiment 6 (on an as-fed basis)

	Req.[a]	Treatment Diet 1 Corn A	Diet 2 Corn B	Diet 3 Corn C	Diet 4 Corn D
Wt, kg		30.67	29.24	29.57	29.86
Ingredient (percent)					
Corn		90.48	90.48	90.48	90.48
Casein, dried		5.04	5.04	5.04	5.04
Calculated values					
DE[b], kcal/kg	3,399	3398	3398	3398	3398
Percent CP		12.67	13.00	13.27	12.90
Percent Digestible Lys	1.07	1.18	1.31	1.36	1.30
Percent total P	0.53	.70	.70	.70	.70
Analyzed values					
DE, kcal/kg		3517	3747	3584	3568
Percent Crude Protein		12.44	12.68	13.17	13.00

[a] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[b] Data on digestible energy of corn, sorghum, and casein was from NRC (1998).

Source: Carter, S.D., J.S. Park, M.J. Rincker, and R.W. Fent. "Energy and Nitrogen Balance of Pigs Fed Four Corn Grains." 2001. *Animal Science Research Report*.

Experiment 7. The initial purpose of this experiment was to determine the energy and nitrogen balance of three commercially available corn hybrids (A, B, and C) by feeding pigs with three dietary treatments, each containing one of the three corn hybrids at 90.48 percent. Diet 1 contains hybrids A corn, Diet 2 contains hybrids B corn, and Diet 3 contains hybrids C corn. All three diets have CP values of about 12 percent but have been supplemented with amino acids to met NRC recommendations. Casein and amino acids were added to the diets to meet or exceed the NRC (1998) amino acid requirements, and limestone and dicalcium phosphate were utilized as sources of calcium and phosphorus (Carter *et al*., 2000).

Table IV-8. The Nutrient Composition of the Grains and Diets in Experiment 7 (on an as-fed basis)

	Req.[b]	Treatment Diet 1 Corn Hybrid A	 Diet 2 Corn Hybrid B	 Diet 3 Corn Hybrid C
Wt, kg		29.12	28.43	29.08
Ingredient (percent)				
Corn[a]		90.48	90.48	90.48
Casein, dried		5.04	5.04	5.04
Calculated values				
DE[c], kcal/kg	3,399	3,398	3,398	3,398
Percent CP		12.03	11.86	11.92
Percent Digestible Lys	1.07	0.94	0.94	0.94
Percent total P	0.53	.70	.70	.70
Analyzed values				
DE, kcal/kg		3,464	3,485	3,430
Percent CP		12.76	12.18	12.38

[a] Corn Hybrids A, B, and C were added to constitute the three diets.
[b] True ileal digestible AA requirements, Table 10-1, NRC (1998).
[c]Data on digestible energy of corns was from NRC (1998).

Source: Carter, S.D., J.S. Park, M.J. Rincker, and R.W. Fent. "Determination of the Metabolizable Energy Concentration of Three Corn Hybrids Fed to Growing Pigs." 2000 *Animal Science Research Report*. Pp123-128.

Experiment 8. This experiment was initially designed to determine the energy and nitrogen balance of pigs fed one corn and two sorghum samples grown within a 50-mile radius in southwest Kansas and the Oklahoma panhandle during the same crop year. The experimental diets consisted of mill-run corn (C), mill-run red sorghum (RS), or an identity-preserved white endosperm sorghum variety (WS) at 90.0 percent of the diet to estimate available energy of grain sorghum, which is more easily grown and a more economically feasible energy source in swine diets in the southern portion of the United States. All experimental diets were formulated to contain 0.98 percent digestible Lysine. Diet 1 (14.0 percent and 0.60 percent CP and total P respectively) contains corn. Diet 2 (14.9 percent and 0.60 percent CP and total P respectively) contains red sorghum. Diet 3 (14.9 percent and 0.60 percent CP and total P respectively) contains white sorghum. Casein was included at 6.14 percent of each diet and amino acids were added to the diets to meet or exceed NRC amino acid requirements, as shown in Table IV-9. Limestone and dicalcium phosphate were utilized as sources of calcium and phosphorus. Dry matter, gross energy concentration, and total nitrogen content were determined for three grain samples and treatment diets. The energy and crude protein concentrations of the corn grain, red sorghum, and white sorghum on an as-fed basis are given in Appendix Table A-66. The digestible energy and crude protein concentrations for the three respective diets on an as-fed basis are shown in the Table IV-9 (Carter *et al*., 2001).

Experiment 9. Hemicell® is an enzyme, which can degrade beta-mannans and improve the efficiency of growing-finishing pigs fed the corn-SBM diet (Hahn et al., 1995; Pettey et al., 2000). Soybean meal may contain 1.3 – 1.7 percent beta-mannans on a dry matter basis according to Carter et al. (2000). Pigs within a litter were blocked by weight and allotted randomly to four dietary treatments to evaluate the effects of Hemicell® addition to corn-SBM diets on energy and nitrogen balance in growing pigs, and to quantify the metabolizable energy (ME) concentration of a corn-SBM diet with Hemicell®. All diets have approximately 18 percent CP. Diet 1 which served as the control was a fortified corn-soybean meal diet. Diet 2 and 3 were the same as Diet 1 with cornstarch added to the daily ration of each pig to increase the ME concentration either by 100 kcal/kg or by 200 kcal/kg in Diet 1. Diet 4 was the control diet added with Hemicell® (.05 percent). Limestone and dicalcium phosphate were utilized as sources of calcium and phosphorus. The digestible energy and crude protein concentrations for the four respective diets on an as-fed basis are shown in Table IV-10. The total 22-day sampling period consisted of two 5-day collection periods. The first collection was conducted on day 4 and continued through day 8. The second collection period began on day 18 and continued through day 22 (Carter *et al*., 2000).

Table IV-9. The Nutrient Content and Ingredient Composition of the Diets in Experiment 8 (on an as-fed basis)

	Req.[d]	Treatment Diet 1 Corn&Casein	 Diet 2 RS[b]&Casein	 Diet 3 WS[c]&Casein
Wt, *kg*		27.91	28.10	27.31
Ingredient (percent)				
Corn or sorghum[a]		90.00	90.00	90.00
Casein, dried		6.14	6.14	6.14
Calculated values				
DE[e], kcal/kg	3,399	3,426	3,296	3,296
Percent CP		13.97	14.87	14.89
Percent Digestible Lys	1.07	0.98	0.98	0.98
Percent total P	0.53	.60	.60	.60
Analyzed values				
DE, kcal/kg		3,539	3,300	3,352
Percent CP		13.39	14.71	14.77

[a]Corn, red sorghum, and white sorghum were added to constitute the three diets.
[b] RS refers to red sorghum used in the experiment.
[c] WS refers to white sorghum used in the experiment.
[d] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[e] Data on digestible energy of corn, sorghum, and casein was from NRC (1998).

Source: Carter, S.D., B.K. Senne, M.J. Rincker, and R.W. Fent. "Energy and Nitrogen Balance of Pigs Commercial Red Sorghum, Identity-Preserved White Sorghum, or Corn." 2001 *Animal Science Research Report*. Oklahoma State University.

Table IV-10. The Nutrient Content and Ingredient Composition of the Diets in Experiment 9 (on an as-fed basis)

	Req.[c]	Treatment[b] Diet 1 Corn&SBM	Diet 2 CS1+Corn&SBM	Diet 3 CS2+Corn&SBM	Diet 4 Corn&SBM+Hl
Wt, kg (1)[e]		31.11	31.02	31.93	31.02
Wt, kg (2)		40.18	39.55	40.73	39.18
Ingredient %					
Ground corn		66.65	66.65	66.65	66.65
SBM,dehulled		30.68	30.68	30.68	30.68
Cal.Phosphate		1.09	1.09	1.09	1.09
Cornstarch[a]		.05	.05	.05	.05
Calculated values					
DE, kcal/kg	3399	3462	3669	3740	3456
Percent CP		18.76	17.98	17.98	17.82
Digt.Lys[d], %	1.03	0.97	0.95	0.92	0.97
Total P, %	0.52	0.60	0.60	0.60	0.60

[a]Cornstarch was added to the daily rations to provide 100 or 200 kcal/kg ME in Diets 2 and 3. Hemicell® replaced cornstarch in Diet 4 and provided 89 million IU/ton.
[b]Diet 1 = fortified corn-SBM diet; Diet 2 = Diet 1 plus 100 kcal/kg ME from cornstarch; Diet 3 = Diet 1 plus 200 kcal/kg ME from cornstarch; Diet 4 = Diet 1 plus Hemicell® at .05 percent.
[c] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[d] Digt Lys = digestible Lysine.
[e] The (1) and (2) refer to the first and second collection period.

Source: Carter, S.D., B.K. Senne, and L.A. Pettey. "Effects of Hemicell® Addition to Corn-Soybean Meal Diets on Energy and Nitrogen Balance in Growing Pigs." 2000 *Animal Science Research Report*. Pp 117-122. Oklahoma State University.

Experiment 10. Experiment 10 was designed to evaluate the effects of solid-state fermented phytase addition on growth performance and phosphorus (P) excretion of pigs fed corn-soybean meal based diets. Phytases were an enzyme, commonly used in swine diets to improve P digestibility. (Lei et al., 1993; Cromwell et al., 1995; O'Quinn et al., 1997). In the 33-day experiment, pigs were blocked by weight and allotted randomly to seven dietary treatments. Diet 1, the basal diet, was formulated with corn and soybean meal contained 0.34 percent total P (0.07 percent available P). The basal diet was adequate in all nutrients, except Ca and P, both of which were provided by corn and soybean meal. Diets 2 to Diet 4 were the same as Diet 1 with monosodium phosphate (MSP) added to the ration to provide 0.05 percent, 0.10 percent, and 0.15 percent added available P. Diets 5 to Diet 7 were the basal plus enzyme to provide 250, 500, and 1,000 phytase units (PU)/kg, respectively. The first collection was conducted on day 10 and continued through day 15. The second collection period began on day 25 and continued through day 30 (Carter *et al*., 2003).

The average body weight of barrows used in these experiments was 32 kg, as shown in the Table IV-12. Also shown in the Table IV-12 were the characteristics of the diet, DM, DE, CP and P contents. Results from the first nine swine feeding trials will be used to estimate changes in growth variables (daily N retention and body weight gain) during the growing-finishing period as dietary nutritional contents change. The data on total phosphorus intake and retention in grams per day recorded in experiment 1, experiment 2, and experiment 5 will be used to estimate daily P retention. The data of experiment 10 will be used to quantify the effect of phytase on P absorptability. The CP and P content curves in Figure IV-1 illustrated different dietary CP and P contents for different diets used in the experiments. Figure IV-2 shows there is a fairly even coverage of DE levels between 3 and 4 kcal per gram over the range of pig weighting from 21 to 40 kg.

Table IV-11. The Nutrient Content and Ingredient Composition of Diets in Experiment 10 (on an as-fed basis)

	Req.[e]	Treatments[a] Diet 1 Corn-SBM	Diet 2 Corn-SBM	Diet 3 Corn-SBM	Diet 4 Corn-SBM	Diet 5 Corn-SBMPT1	Diet 6 Corn-SBMPT2	Diet 7 Corn-SBMPT3
Ingredient %								
Corn		72.07	72.07	72.07	72.07	72.07	72.07	72.07
Soybean meal		25.25	25.25	25.25	25.25	25.25	25.25	25.25
Corn starch		1.16	0.78	0.39	0.00	1.14	1.11	1.06
MSP[b]		0.00	0.21	0.43	0.66	0.00	0.00	0.00
SSF phytase[c]		0.00	0.00	0.00	0.00	0.03	0.05	0.10
Calculated values								
DE, kcal/kg	3400	3492	3397	3521	3506	3495	3549	3439
Percent CP		17.98	17.98	17.98	17.98	17.98	17.98	17.98
Percent lysine	0.83	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Percent Ca		0.41	0.47	.53	.59	.41	.41	.41
Percent total P[d]	0.50	0.34	0.39	.44	.49	.34	.34	.34
Available P, %	0.19	0.07	0.12	.17	.22	.07	.07	.07
Phytase, PU/kg		0	0	0	0	250	500	1000
Analyzed Value								
Percent total P		0.37	0.43	0.48	0.52	0.37	0.37	0.37

[a] Provided the following per kg of diet: 5,506 IU of vitamin A, 551 IU of vitamin D, 33 IU of vitamin E, 3.6 mg of vitamin K (as menadione), 221 mg of biotin, 137 mg of choline, 33.04 mg of niacin, 24.78 mg of panthothenic acid (as d-pantothenate), 5.51 mg of riboflavin, 27.55 mg of vitamin B12, 1.66 mg of folacin, 100 mg of Zn, 2 mg of Mn, 100 mg of Fe, 10 mg of Cu, .30 mg of I, and .30 mg of Se.

[b] MSP is monobasic sodium phosphate.

[c] Solid-state fermented phytase (Allzyme® SSF; Alltech, Inc) contains 1,000 PU/g of product.

[d] Analyzed total P were 0.37, 0.43, 0.48, 0.52, 0.37, 0.37, and 0.37 percent, respectively.

[e] Total and available phosphorus requirements, Table 3-2, NRC (1998).

Source: Carter, S.D., J.D. Schneider, J.S. Park, and T.B. Morillo. "Effects of Solid-State Fermented Phytase on Phosphorus Utilization in Growing Pigs Fed Corn-Soybean Meal Diets: I. Growth Performance and Phosphorus Excretion." 2003 *Animal Science Research Report*. Oklahoma State University.

Table IV-12. Summary of initial body weight, and DM, DE and CP content for each diet of the swine feeding trials.

Diet	BW[b], kg	DLysCont	CPCont	PCont	DEI	DBWG	PR	NExc	PExc
Corn&Casein	27.9	0.01001	0.134	0.006	4709.2	554.1	129.9	7.7	--
Corn&SBM+Hl	35.1	0.00969	0.178	0.006	5547.0	884.4	151.2	21.6	--
Corn&SBMH	39.5	0.00848	0.140	--	6419.2	1034.8	202.8	13.9	--
Corn&SBMP	39.7	0.00813	0.140	0.007	6565.6	1086.9	203.2	13.0	--
Corn&SPC	28.1	0.00859	0.132	0.005	5437.7	797.9	142.3	10.9	3.37
Corn&SPI	32.1	0.00818	0.152	0.005	4909.0	865.2	126.0	10.9	1.97
Corn+CS&Casein	28.9	0.00890	0.171	0.005	5962.2	909.0	197.8	6.4	--
CornA	30.7	0.00832	0.124	0.007	4831.8	812.0	117.6	8.5	--
CornB	29.2	0.00877	0.127	0.007	4694.6	705.9	108.3	8.1	--
CornC	29.6	0.00870	0.132	0.007	4817.0	868.0	124.2	8.5	--
CornD	29.9	0.00886	0.130	0.007	4210.8	683.2	103.2	8.0	--
CornHA	29.1	0.00855	0.128	0.007	3965.4	396.0	97.1	7.8	--
CornHB	28.4	0.00855	0.122	0.007	3867.9	363.6	89.3	7.3	--
CornHC	29.1	0.00854	0.124	0.007	4084.0	318.1	93.8	8.6	--
Corn-SBM	32.6	0.00922	0.186	0.006	5720.9	907.8	182.2	18.8	3.49
CS&Casein	25.5	0.00880	0.167	0.003	5548.0	676.4	153.3	1.9	0.69
CS&Casein+SBM	30.3	0.00867	0.203	0.005	5341.2	841.6	205.1	7.1	2.06
CS&SBM	37.8	0.00802	0.141	0.004	6384.3	1019.8	165.2	11.7	2.34
CS&SBMH	37.8	0.00797	0.138	0.005	6705.0	1101.8	160.4	13.0	3.05
CS&SPC	35.8	0.00768	0.133	0.004	6210.8	982.3	152.2	9.9	1.96
CS&SPI	36.1	0.00754	0.143	0.004	5516.0	963.5	149.4	9.0	1.85
CS1+Corn&SBM	35.3	0.00945	0.180	0.006	6004.9	879.8	162.2	21.1	--
CS2+Corn&SBM	36.3	0.00923	0.180	0.006	6259.7	927.4	166.6	21.5	--
LPAA	31.8	0.00830	0.148	0.005	5941.8	929.7	158.6	12.5	3.28
RS&Casein	28.1	0.00979	0.147	0.006	4532.3	588.1	142.3	9.5	--
WS&Casein	27.3	0.00979	0.148	0.006	4455.7	646.3	135.8	9.7	--
Corn&SBMPT[c]	--[a]	0.00950	0.180	0.004	--	725.1	--	--	--

Table IV-12. (*continue*)

Diet	BW[b], kg	DLysCont	CPCont	PCont	DEI	DBWG	WBPG	NExc	PExc
Average value	31.64	0.00875	0.149	0.005	5360.6	773.1	150.0	12.1	2.36

Soucre: Carter et al. (1999, 2000, 2001, 2003).

[a] Dash indicates no data.

[b] BW = body weight in kg. DMCont = dry matter content in the diets. DECont = digestible energy content in the diet. LysCont = digestible lysine content in the diets. CPCont = CP content in the diets. PCont = total phosphorus content in the diets. DEI = daily DE intake (kcal/day). DBWG = daily body weight gain (g /d). PR = daily body protein gain (g/d). NExc = daily N excretion (g/d). PExc = daily P excretion (g/d).

[c] Corn&SBMPT is referring to the corn-SBM diets added with solid-state fermented phytase in the Experiment 10

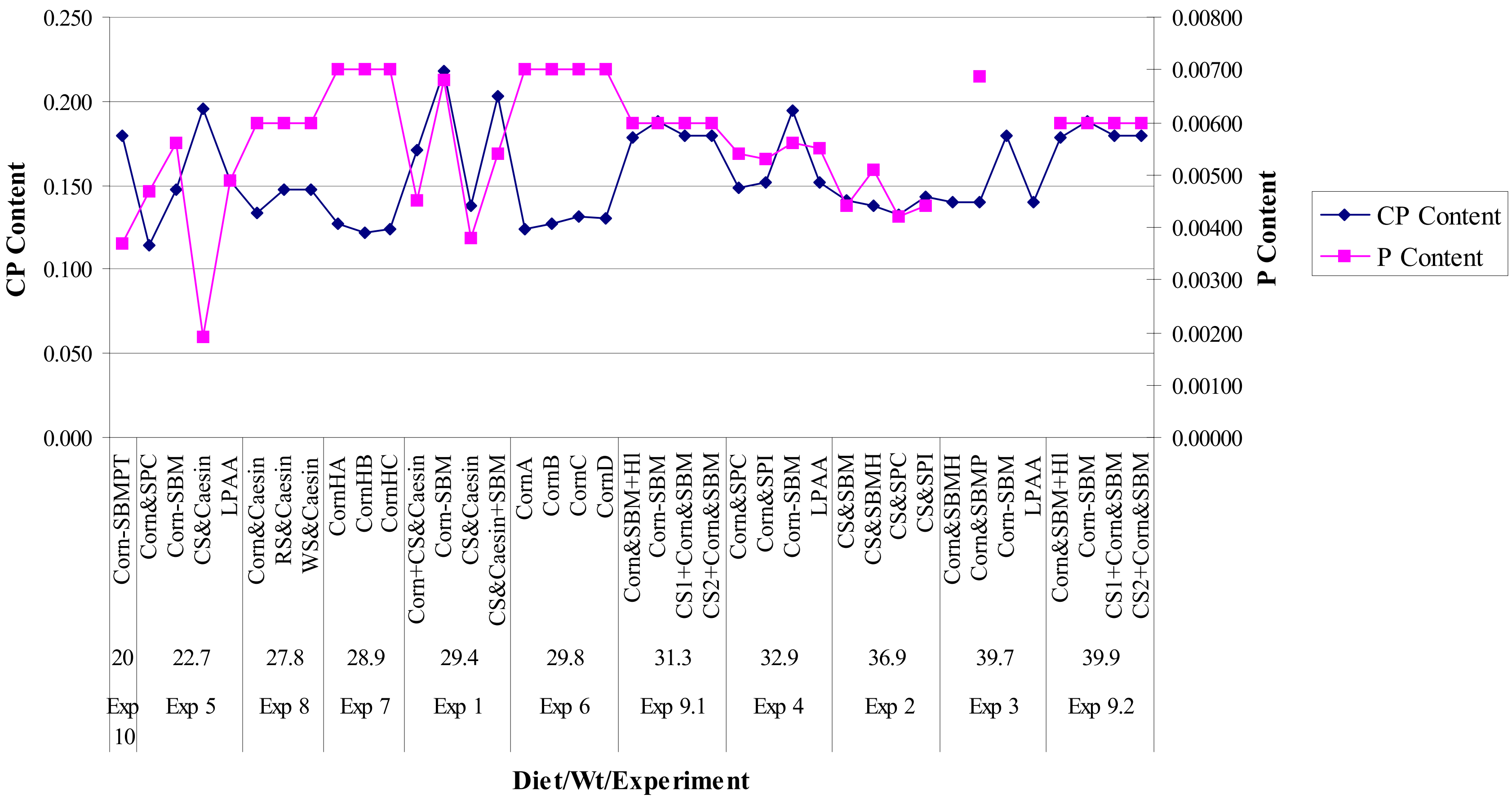

Figure IV-1. **The dietary crude protein and phosphorus contents (percent of feed) of different diets used in the experiments (Carter *et al*. 1999; 2000; 2001; 2003).**

Ad Libitum DE intake, Protein and P Retention in the NRC Model

The difference between predicted and experimental results for each performance variable will be analyzed as a randomized block design using an analysis of variance procedure as described by Snedecor *et al*. (1967). The performance variables analyzed in this study were daily feed intake (DFI, in grams/day), daily body nitrogen retention (DNR, in grams/day), daily body weight gain (DBWG, in grams), and the efficiency of feed utilization (G:F, DBWG/DFI) in a certain feeding period. The simulation model uses animal initial body weight to predict the maximal performance values for each growth variable. In the experiments, pigs were fed the dietary treatments for an adjustment period followed by a collection period in which the performance variables were measured. The simulation model assumes pigs maintain maximal growth during the feed adjustment period, and calculates the average value of each performance variable in the collection period following the adjustment period.

For growing-finishing pigs allowed ad labitum access to feed, daily feed intake (DFI_t, grams/day) is determined by energy requirement and the energy content of diets according to the NRC. Pigs typically would not eat after their energy requirements are satisfied. The maximum digestible energy intake (MxDEI) for a combination of barrows and gilts assumed to be entirely dependent on pig body weight was described by the National Research Council (1987) and Agricultural Research Council (1981) as follows:

$$\begin{aligned} &\text{Maximum DE Intake (MxDEI, kcal/day)} \\ &= 13162 \times (1 - e^{-0.0176BW_t}) \end{aligned} \quad . \qquad (4\text{-}1)$$

The maximum DE intake was estimated by the NRC in exponential equation (4-1) and quadratic equation (2-4). Since these equations are very similar, the DE intake of the exponential equation was chosen for the simulation model.The DE content of each diet in the experiments was calculated by the composition of diets and digestible energy contents in feedstuffs obtained from the NRC and Heartland Lysine, Inc. The values of feed intake were obtained by dividing the requirements for DE predicted with the growth model by the estimated DE content in diets. That is,

$$\text{DFI (g/day)} = \text{Maximum DE intake / DE content of Diet.} \qquad (4\text{-}2)$$

The average daily feed intake was estimated from cumulative feed intake during the collection period.

The daily body protein retention (PR_t , in grams/day) is comparable to the whole body protein gain, $WBPG_t$, in the simulation model. That is, the daily body protein retention in grams per day, PR_t , can be predicted from the whole body protein generating equation:

$$\begin{aligned} PR_t\,(\text{g/day}) = {} & (17.5 \times e^{-0.0192 BW_t} + 16.25) \times [0.008 \times (\text{MFFL}/2.55)] \times \\ & (1 + 0.015 \times (20 - T) \times \\ & (\text{MxDE intake} - 0.55 \times \text{DE req. for maintenance}), \end{aligned} \qquad (4\text{-}3)$$

where MFFL expressed in grams per day is the mean carcass fat free lean accretion rate, and could be estimated using initial and final carcass fat-free lean.

The relationship was used to calculate average daily protein retention for pigs of different initial body weights. Genotypes and ambient temperature are two other factors that jointly determine daily protein retention. To best compare simulation results with experimental results, pig's genotype and temperature in the simulation model were fixed at the same levels as in the experiments. That is, ambient temperature in the body protein retention equation was set to be the same value as the experiments, $24^0 C$. The equation to calculate daily protein retention, PR_t, during the growing-finishing period from average feed intake, given a body weight, a certain mean fat free lean growth rate, and $24^0 C$ ambient temperature is as follows:

$$PR_t = (17.5 \cdot e^{-0.0192BW_t} + 16.25) \times (0.003137 \cdot MFFL) \times \\ 0.94 \times (\text{MxDE intake - } 0.55 \times \text{DE req. for maintenance}). \tag{4-4}$$

The effect of temperature on whole body protein accretion rate in the equation (3-3), $1 + 0.015 \times (20 - 24)$, was simplified to 0.94, and works as the parameter of DE intake above 55 percent of DE requirement for maintenance.

The pigs were assumed to be of the genotype for high lean growth rate with the mean fat-free carcass lean accretion rates (MFFL) specified to be 350 gram per day. The equation for calculating daily PR during the growing-finishing period from maximum feed intake, given an initial body weight, the high fat free lean growth rate of 350 (g/day), and $24^0 C$ ambient temperature is then:

$$PR_t(\text{g/day}) = (17.5 \times e^{-0.0192BW_t} + 16.25) \times (0.003137 \times 350) \times \\ 0.94 \times (\text{MxDE intake - } 0.55 \times \text{DE req. for maintenance}). \tag{4-5}$$

After simplified this becomes

$$PR_t(\text{g/day}) = (18.0628 \times e^{-0.0192BW_t} + 16.7726) \times \\ (\text{MxDE intake - } 0.55 \times \text{DE req. for maintenance}). \tag{4-6}$$

The values of average daily protein retention can also be estimated by some of the biological functions contained in the growth model of Fawcett *et al.* (1978). The estimated whole body protein gains with the body weight gains of the experimental data will then be used in the model validity analysis. The variable of interest, daily nitrogen retention (DNR), is not immediately available from the simulation model. However, since 1 g of nitrogen is assumed to correspond to 6.25 g of protein (Boisen et al., 1999), nitrogen retention can be calculated from protein retention. The daily body protein retention (PR_t) in the simulation model can be converted to the daily nitrogen retention (DNR_t) by dividing it with a coefficient, 6.25. That is,

$$\begin{aligned} &\text{Daily Nitrogen Retention } (DNR_t\text{, gram/day}) \\ &= PR_t /6.25 \\ &= (2.8896 \times e^{-0.0192BW_t} + 2.6832) \times DEA_t, \end{aligned} \quad (4\text{-}7)$$

where DEA_t is digestible energy intake (DE) above 55 percent of maintenance, expressed in grams per Mcal. That is,

$$DEA_t = (\text{MxDE intake - } 0.55 \times \text{DE req. for maintenance}). \quad (4\text{-}8)$$

Daily body weight gain ($DBWG_t$, in grams/day) is the sum of the weight gains of bone, skin, protein tissue, and fat tissue. Fat tissue gains depend on digestible energy intake, and on the energy needed for maintenance and protein retention. Surplus metabolizable energy is converted into fat.

For phosphorus, INRA (1989) assumed an average retention of 6 g phosphorus per kg of weight gain for all types of pigs. The daily requirement (g/day) for bioavailable phosphorus (PHR) based on fortified corn-soybean meal diet was recommended by the NRC (1998) is as follows:

$$\begin{aligned} &\text{Daily P Requirements (PHR, g/day)} \\ &= \text{Req. Concentration} \times \text{Feed Intake (g)} \\ &= \text{Req. Concentration} \times (\text{Maximum DE intake} / 3.4) \\ &= e^{-0.0557-0.416(\ln BW)+0.005(\ln BW)^2} \times 13162 \times (1 - e^{-0.0176BW}) / 3.4. \end{aligned} \quad (4\text{-}9)$$

The phosphorus requirement above was dependent on feed intake. In the growth manipulation model, the growth rate was primarily restricted by energy intake (Calabotta *et al*., 1982). Changes in dietary energy concentration, as the proportions of ingredients changed while maintaining the same daily intake of protein and digestible energy, do not affect growth rates. As energy intake is the factor that restricts the growth of animal with certain body weight, the corresponding phosphorus requirement in the model was more specifically determined by energy intake. It is also possible to estimate the bio-available P requirements according to body weight and expected body weight gain for growing pigs. The daily phosphorus retention (PHR_t, kgs/day) and calcium retention (CR_t, kgs/day) can be described as follows (Jongbloed, 1987):

$$PHR_t \text{ (kg/day)} = 0.003467BW^{-0.025}DBWG_t \qquad (4\text{-}10)$$

$$CR_t \text{ (kg/day)} = 0.007996BW^{-0.005}DBWG_t \qquad (4\text{-}11)$$

The Simulated DE intake, Protein and P Retenion with the Initial NRC Model

Daily feed intake, body weight gains, phosphorus retention, and nitrogen retention of a growing-finishing pig were estimated by simulating each individual pig with certain initial body weight for each dietary regimes. Detail values of simulated DFI, DBWG, and daily N retention from the unadjusted NRC model for each diet of the experiments were shown in Appendix Table A4-20. The average values of calculated DFI, DBWG, and daily N retention for each diet of the experiments were shown in Table IV-13.

Table IV-13. The Average Experimental and Simulated Values of Growth Variables for Different Diets from the Unadjusted NRC Model.

	Experiment				Simulation			
Diets[d]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
CS&Caesin	676.4	24.5	1460.5	0.47	906.0	22.2	1583.1	0.57
WS&Casein	646.3	21.7	1329.2	0.49	849.4	20.6	1704.7	0.50
Corn&Casein	554.1	20.8	1330.8	0.42	858.2	20.8	1635.3	0.53
RS&Casein	588.1	22.8	1373.6	0.42	858.7	20.8	1757.3	0.49
Corn&SPC	797.9	22.8	1581.4	0.51	960.7	23.2	1890.3	0.51
CornHB	363.6	14.3	1110.0	0.33	904.3	21.7	1766.0	0.51
Corn+CS&Casein	909.0	31.7	1556.6	0.58	934.7	22.3	1677.3	0.56
CornHC	318.2	15.0	1190.6	0.26	913.1	21.9	1819.6	0.50
CornHA	396.0	15.5	1144.4	0.35	914.2	21.9	1805.1	0.51
CornB	705.9	17.3	1252.7	0.56	914.2	21.9	1667.3	0.55
CornC	868.0	19.9	1344.3	0.64	915.2	21.9	1752.6	0.52
CornD	683.2	16.5	1180.3	0.57	923.5	22.1	1774.1	0.52
CS&Casein+SBM	841.6	32.8	1354.6	0.62	962.5	22.9	1687.4	0.57
CornA	812.0	18.8	1373.8	0.57	940.4	22.4	1837.1	0.51
LPAA	929.7	25.4	1730.7	0.53	996.5	23.7	2008.9	0.50
Corn&SPI	865.2	20.2	1434.0	0.61	1013.6	24.0	2057.2	0.49
Corn&SBM	907.8	29.2	1627.0	0.57	994.6	23.5	1980.8	0.51
Corn&SBM+Hl	884.3	24.2	1605.0	0.56	1014.7	23.6	2097.4	0.49
CS1+Corn&SBM	879.8	26.0	1636.6	0.54	1021.9	23.8	1989.8	0.52
CS&SPC	982.3	24.4	1614.3	0.61	1036.8	24.2	1907.9	0.54
CS&SPI	963.5	23.9	1434.5	0.68	1037.9	24.2	1914.1	0.54
CS2+Corn&SBM	927.4	26.7	1673.8	0.56	1032.3	24.0	1980.8	0.53
CS&SBMH	1101.8	25.7	1758.5	0.63	1056.6	24.6	1979.0	0.53
CS&SBM	1019.8	26.4	1687.7	0.60	1053.8	24.5	1991.0	0.53
Corn&SBMH	1034.8	32.5	1883.7	0.55	1077.9	24.9	2273.9	0.47
Corn&SBMP	1086.9	32.5	1922.0	0.57	1081.1	25.0	2277.3	0.47
Average value	795.1	24.0	1506.2	0.52	964.6	22.9	1883.9	0.52

[a]ADNR is the average daily nitrogen retention in grams per day. ADFI is the average daily feed intake in grams per day. G:F is the efficiency of feed utilization (ADG/ADFI).
[b]Data concerning Experiment 9-1 corresponds to the first collection period of the experiment 9.
[c]Data concerning Experiment 9-2 corresponds to the second collection period of the experiment 9.
[d]Diets were sorted by weight.

The NRC swine growth and nutrient requirement model is based on farm level data on the standard Corn-Soybean Meal (Corn-SBM) diet. The values of growth variables predicted by the simulation model, therefore, may represent the growth levels of pigs fed the corn-SBM diet on farms. In the experiments conducted by Carter *et al.*

(1999; 2000; 2001; 2003), average daily body-weight gains, average daily feed intake, ration compositions, average daily nitrogen intake, average daily nitrogen retention, average daily dry matter intake, and dry matter excreted during a certain feeding period were recorded. The calculated nutrient retention is the total amount of nutrient provided by the diet minus the amount excreted from the animal. The nutrient excretion is the total nutrient excretion by the animal, which includes indigestible, unbalanced and excess nutrient losses as well as the amount of nutrients excreted due to maintenance, and endogenous losses. The average results for each diet of the experiments were also given in the Table IV-13. Three experiments (Exp1, Exp2, and Exp5) recorded phosphorus intake and retention. The measured and simulated values of phosphorus retention are shown in the Table IV-14.

Dietary Effects on the Predictability of Initial NRC Model

We define the differences between actual and simulated growth variables as follows:

DFADFI = experimental ADFI – simulated ADFI,

DFADNR = experimental ADNR – simulated ADNR,

DFADG = experimental ADG – simulated ADG,

DFAPHR = experimental APHR – simulated APHR,

DFG:F = experimental G:F – simulated G:F.

Table IV-14. Difference between the Simulated and Actual Phosphorus Retention, g/d.

Diet	Simulation			Experiment	Difference[c]
	TP[a], g/d	PHR(1)	PHR(2)[b]		
Corn&SPC	9.55	4.06	4.40	6.18	1.78
Corn+CS&Caesin	5.60	4.19	4.25	3.64	-0.61
Corn-SBM	8.71	4.08	4.23	5.23	1.00
CS&Casein	3.56	4.08	4.17	2.86	-1.30
CS&Casein+SBM	6.06	4.27	3.71	4.00	0.29
CS&SBM	7.43	4.49	4.06	5.10	1.04
CS&SBMH	8.87	4.50	4.27	5.82	1.55
CS&SPC	6.68	4.45	4.04	4.73	0.69
CS&SPI	6.33	4.45	3.57	4.48	0.91
LPAA	7.83	4.01	4.27	4.55	0.28
Average value	7.06	4.23	4.12	4.58	0.46

[a] TP is the actual value of daily total phosphorus intake, in gram per day.
[b] PHR(1) is the average daily phosphorus retention in grams per day calculated by the simulated digestible energy intake. PHR(2) is the average daily phosphorus retention in grams per day calculated by the actual digestible energy intake.
[c] Difference is the difference in average daily phosphorus retention in grams per day between experimental and simulation value calculated by the actual digestible energy intake. That is, difference = experimental PHR- simulated PHR(2).

The differences between the measured and calculated values of the daily body weight gain, daily nitrogen retention, daily feed intake, and feed conversion efficiency for individual pigs in all experiments are shown in Appendix Table A4-22. The relationship between the actual and predicted digestible energy intake (DEI) levels is shown in Figure IV-2. Figure IV-2 shows that on average, the simulated average daily DE intake was higher than the experimental ADFI for each diet in the nine experiments, except the diets of CS&Casein and Corn+CS&Casein. The unadjusted NRC model over-estimated daily DE intake and consequently over-estimated ADBWG, but under-estimated ADNR.

However, the predicted efficiency of gain was on average equal to the observed values. The differences between the measured ADBWG and ADNR, and the simulated ADBWG and ADNR that were calculated by the measured DE intake are shown in

Appendix Table A4-22. Also shown is the simulated body weight gain as well as simulated protein retention (DFADG(2) and DFNR(2)) using actual DE intake. Since the simulation values of growth variables were based on the farm level data on the corn-SBM diet, while experimental ones were obtained from pigs housed in the well controlled metabolism chambers, the differences between experimental and simulation growth levels may represent the effect of difference in growth conditions as well as dietary treatment. Differences in simulated and experimental results, therefore, were compared using a model that included dietary treatments as fixed effects to determine whether diet compositions might contribute to differences in predictability of the simulation model.

To quantify the effects of digestible energy intake on the daily protein retention and daily body weight gain, the simulated daily nitrogen retention and daily body weight gain, calculated by the measured DE intakes (DFADG(2) and DFNR(2)) were used in the regression analysis. The statistical model predicts the difference between predicted and experimental results for each performance variable with the independent variables over a feeding period. The explanatory variables of the model are interaction $\text{Diets} \times \text{Experiment}$ and littermates. Let DF represent the difference between the value of a growth variable observed in the experiment and the simulated value, that is DF = observed – simulated. Mathematically, the basic statistical model can be expressed as

$$\begin{aligned}\text{DF } \textit{growth variable} &= \beta_1 \text{Diets} \times \text{Experiment} + \\ &\quad \beta_2 \text{Littermates} + \varepsilon\end{aligned} \tag{4-12}$$

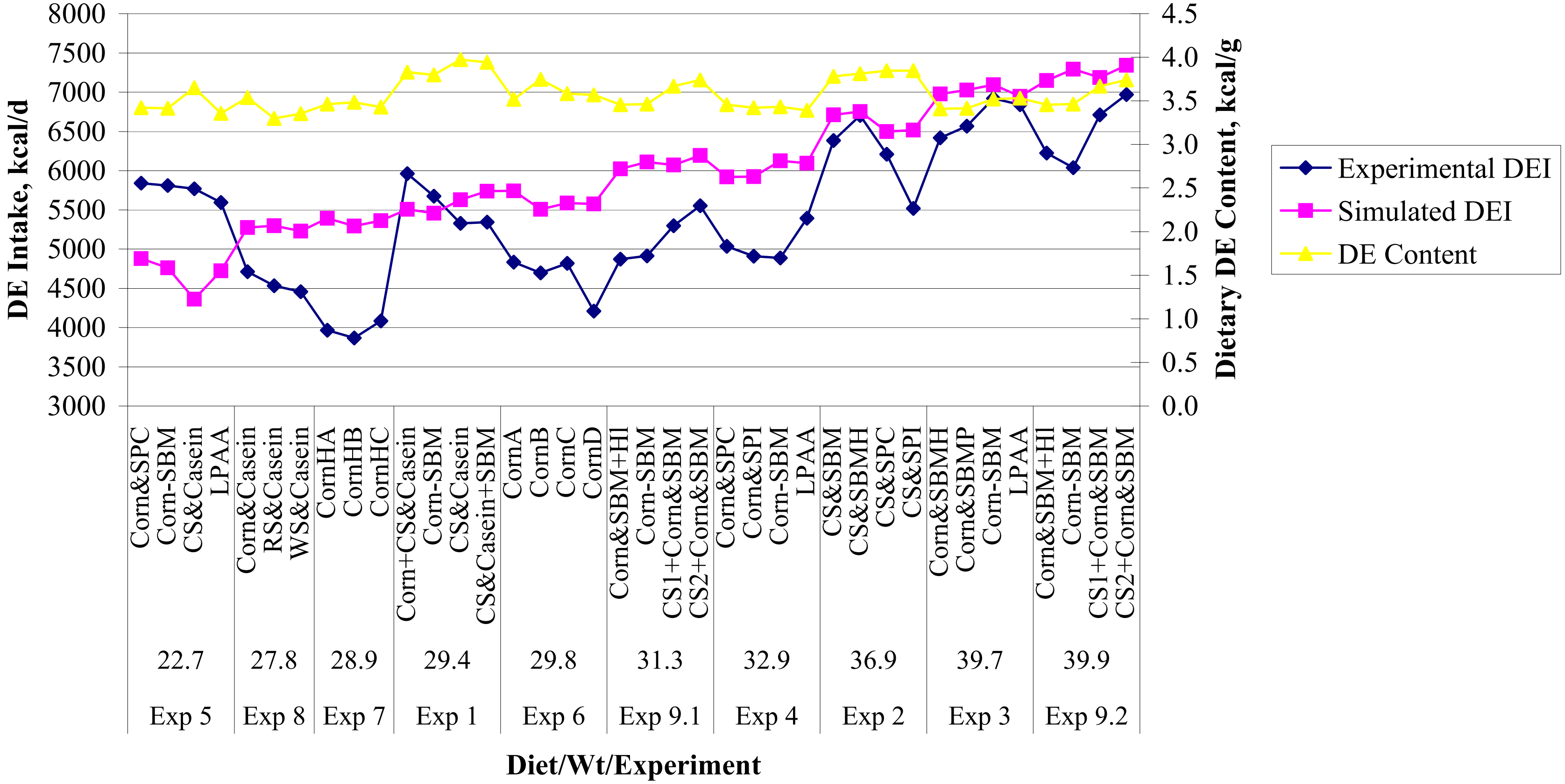

Figure IV-2. The Relationship between actual and simulated DEI, and dietary DE content for different diets, sorted by the animal body weight of the experiments.

The variable,“Littermates”, was included in the model as a random effect, while dietary treatments and experiment will be regarded as fixed effect variables. The benefits of the random effects analysis are that correlation between littermates can be modeled directly, and inferences about fixed effects can be applied to entire populations of pig genotype. To account for possible correlation between littermates, an interclass correlation coefficient will be included in the analysis. Pigs within the same litter were considered as the experimental units. The model can be used for pigs in the weight range of 20 to 120 kg. The analyses of variance including effects of dietary treatments, and littermates were carried out using the SAS procedure MIXED (SAS Inst. Inc., Cary, NC).

To evaluate the NRC simulation model, hypothesis tests were performed to investigate whether the differences between experimental results and the predicted value of the simulation model were significantly different from zero in swine feeding trials of low crude protein and phosphorus rations (Carter *et al*., 1999; 2000; 2001; 2003). If there is not enough evidence to reject the null hypotheses that the intercept and the fixed-effects parameters are zero, then the simulation model may provide reasonable and consistent prediction on growth variables for the profit maximization problem across the dietary treatments.

To evaluate the NRC simulation model, the calculated daily body weight gain, daily nitrogen retention, daily feed intake, and feed conversion efficiency with the growth model developed from the *Nutrient Requirements of Swine* (NRC, 1998) were compared against the experimental results from Carter *et al*. (1999; 2000; 2001; 2003) for all the diets. Detailed simulation and experiment results shown in Appendix Table A4-20 were used to closely examine the ability of the model in predicting pig growth. In addition, the differences between experimental and simulated values for each performance variables of this model (average daily weight gain, daily nitrogen retention, daily feed intake, and feed conversion ratio) were analyzed with a mixed linear model by using data sets of swine feeding trials that included low crude protein and phosphorus rations (Carter *et al*., 1999; 2000; 2001; 2003) to evaluate the simulation model. Hypothesis tests were performed to investigate whether the differences between experimental and predicted values were significantly different from zero. If there is not enough evidence to reject the null hypothesis that the intercept and the fixed-effects parameters (Dietary treatments) are zero, then the simulation model may provide reasonable and consistent prediction. The estimates of intercept and fixed effects parameters, and results of t-hypothesis tests are shown in Table IV-15.

Table IV-15. The estimated parameters of the mixed linear models for the difference between the experimental and calculated values of each performance variable.

Experiment	Diet	DFADFI	DFADNR(2)[c]	DFADG(2)[c]	DFG:F
Exp 5					
22.7 kg	Corn&SPC	-111.1	2.85**	-142.82*	-0.059
	Corn&SBM	-69.1	9.14***	-104.67	-0.042
	CS&Casein	-17.3	0.38	-333.60***	-0.022
	LPAA	-149.2*	1.53	-127.98*	-0.059
Exp 8					
27.8 kg	Corn&Casein	-411.7***	3.81***	-125.74**	-0.101***
	RS&Casein	-481.6***	6.61***	-68.54	-0.069*
	WS&Casein	-481.2***	5.67***	3.87	-0.009
Exp 7					
28.9 kg	CornHA	-730.7***	1.8*	-162.36**	-0.170***
	CornHB	-738.6***	0.84	-165.84**	-0.184***
	CornHC	-717.2***	0.73	-228.92***	-0.228***
Exp 1					
29.4 kg	Corn+CS&Casein	-222.5**	9.49***	6.04	0.028
	Corn&SBM	-250.6***	12.59***	-0.87	0.032
	CS&Casein	-376.2***	6.09***	-46.13	-0.022
	CS&Casein+SBM	-381.1***	13.74***	37.95	0.032
Exp 6					
29.8 kg	CornA	-530.4***	1.93*	127.84*	0.062
	CornB	-488.3***	0.7	34.67	0.006
	CornC	-485.1***	2.87**	179.27**	0.114**
	CornD	-667.3***	2.12*	108.09	0.052
Exp 9.1					
31.3 kg	Corn&SBM+Hl	-420.8***	3.54***	140.93*	0.072
	Corn&SBM	-414.3***	6.97***	228.60***	0.131**
	CS1+Corn&SBM	-286.2***	5.1***	100.56	0.051
	CS2+Corn&SBM	-237.1***	6.31***	88.70	0.050

Table IV-15. (*continue*)

Experiment	Diet	DFADFI	DFADNR(2)[c]	DFADG(2)[c]	DFG:F
Exp 4					
32.9 kg	Corn&SPC	-349.7***	2.45**	97.52	0.059
	Corn&SPI	-652.3***	3.16***	175.72**	0.112**
	Corn&SBM	-704.3***	5.5***	209.15***	0.130**
	LPAA	-554.7***	3.9***	144.84*	0.091*
Exp 2					
36.9 kg	CS&SBM	-315.7***	4.84***	113.02	0.073
	CS&SBMH	-231.9***	2.76**	136.77*	0.092*
	CS&SPC	-314.8***	2.96***	89.76	0.065
	CS&SPI	-500***	5.4***	200.04***	0.140***
Exp 3					
39.7 kg	Corn&SBMH	-391.7***	11.1***	136.97*	0.076
	Corn&SBMP	-355.2***	10.71***	166.60**	0.093*
	Corn&SBM	-263.1***	12.32***	31.17	0.026
	LPAA	-243.6***	7.04***	138.46*	0.077
Exp 9.2					
39.9 kg	Corn&SBM+Hl	-614.7***	7.98***	103.42	0.062
	Corn&SBM	-696.8***	7.72***	167.28**	0.095*
	CS1+Corn&SBM	-461.3***	6.33***	-29.07	0.001
	CS2+Corn&SBM	-406.9***	5.01***	5.41	0.021
Diets *P*[a]		0.0001	0.0001	0.0001	0.0001

The probability of a significant treatment effect are indicated by * P<0.05, ** P<0.01, *** P<0.001.

[a] The *p*-value of Type 3 tests for the fixed effect.

[c] The estimate for the last diet equal 0 due to over parameterization.

[d] DFADNR(2) and DFADG(2) are simulated by using the actual DE intake values from each experiment rather than using the DE intake levels predicted by the NRC simulation model

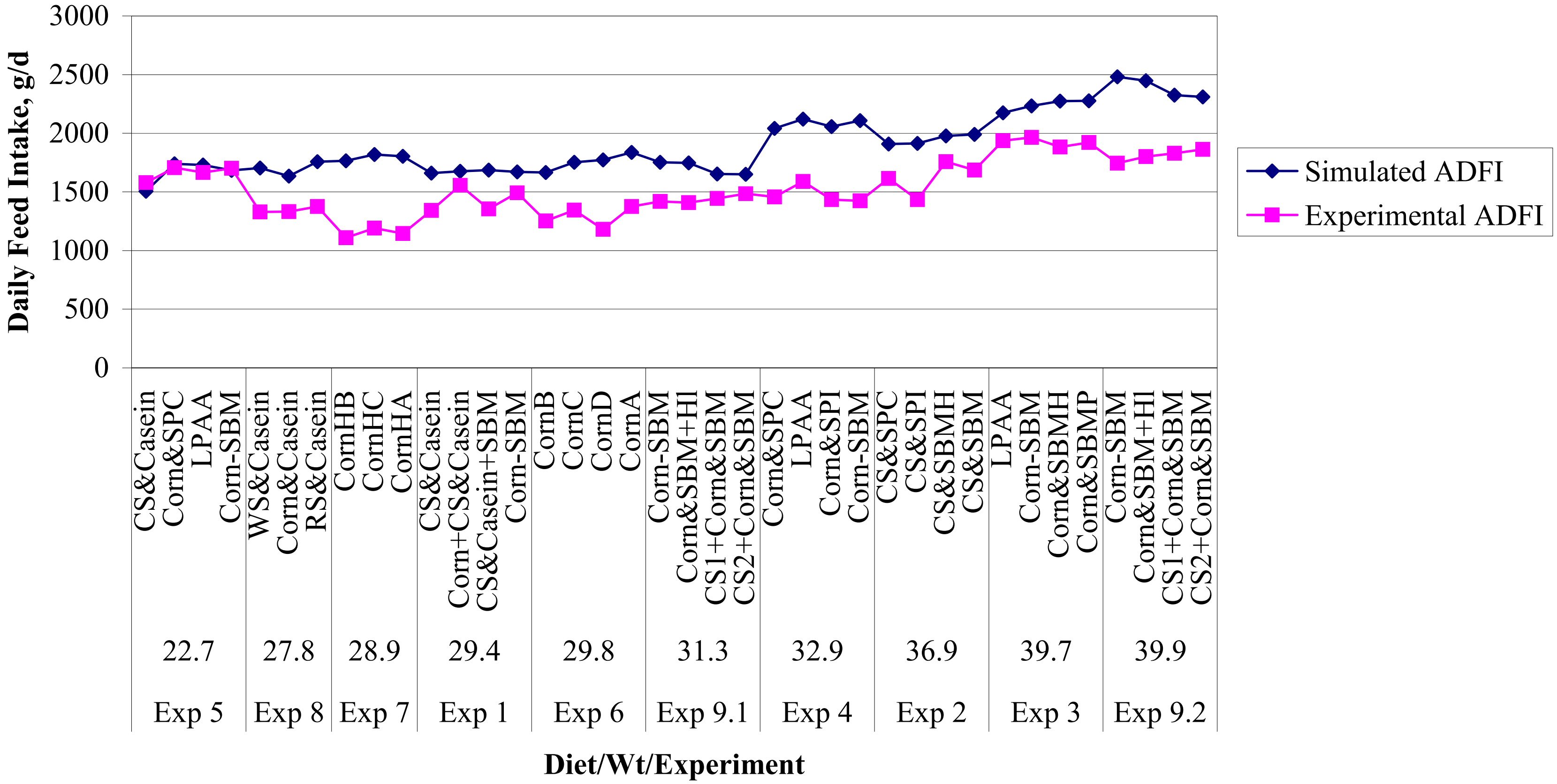

Figure IV-3. The relationship between experimental and simulated ADFI in gram per day for different diets, sorted by animal weight.

Experimental Vs Simulated Daily Feed Intake

Given a diet with a particular digestible energy content, the simulation daily feed intake (DFI_t, grams/day) was estimated by daily digestible energy intake of pigs, which was assumed to be entirely dependent on pig body weights (NRC, 1998). From Table IV-15, it can be seen that the experimental ADFI was significantly lower than simulated ADFI for the typical corn-SBM diet at five percent level, except the experiment 5. The assumption is that pigs in the metabolism chambers of the laboratory consumed less feed than those raised on farm. In the experiment 5, the difference between measured and simulated ADFI was insignificant, and the value were similar among pigs fed with the low CP diets of CS&Casein, Corn&SPC and LPAA, or Corn-SBM diet. The measured ADFI was significantly lower than the simulated ADFI for pigs fed with the diets of low CP as well as Corn-SBM diet in all other experiments. The higher simulated ADFI may be attributed to both dietary treatment and metabolism chamber effects. To isolate the effects of dietary treatments, a regression model similar to equation (4-12) but including an intercept term was analyzed. The intercept was interpreted as the overall difference between experimental and simulated ADFI due to difference in growing condition between pigs raised in farms and metabolism chambers. The results of second regression analysis show that the difference between measured and simulated ADFI significantly increased in the diets of Corn&SPI, CornD, CornHA, CornHB, and CornHC and significantly decreased in the diets of Corn&SPC, Corn+CS&Casein, CS&Casein, LPAA, CS&SBM, CS&SBMH, CS1+Corn&SBM, CS2+Corn&SBM and CS&SPI at five percent level. Other dietary treatments did not significantly affect the predictability of the simulation model in ADFI, though the null hypothesis that the overall difference between experimental and simulated ADFI for all diets is zero was rejected by the data ($p<0.0001$). Since the simulated value of daily feed intake was calculated by pig body weights, variation in the difference between measured and simulated ADFI for different diets suggests that actual feed intake may also be influenced by dietary nutrient content as well as animal body weight. The actual DE intake and thereby feed intake of pigs fed with the diets of CS&Casein, Corn&SBM+H1, Corn&SPC, Corn&SPI, and LPAA, in which both the DE and CP content were lower than the Corn-SBM diet was increased, as shown in Figure IV-3. For the diets of Corn&SPI, CornD, CornHA, CornHB, and CornHC, in which both the DE and CP content were strictly reduced, the actual feed intake of pigs decreased.

The low predictability of the simulation model for daily feed intake may arise from invalid parameter estimation of maximum DE intake equation as well as incorrect estimation of DE contents of the diets. Since some of the experimental data of Carter *et al*. does not include analyzed values of DE contents in diets, the digestible energy values of feed ingredients that have been reported by NRC (*Nutrient Requirements of Swine*, 1998) were used to calculate the DE content of the diets. As a wide range of digestible energy values was observed for feed ingredients (Kim et al., 1999; Carter et al., 2002), depending on their area of origin, any variability in digestible energy contents of the feed ingredients used could have large effects on the estimation of average daily feed intake (Cromwell et al., 1999). Thus, the determination of digestible energy content of diets would require more accurate determination of energy contents of feed ingredients.

Experimental Vs Simulated Daily Nitrogen Retention

Given a certain mean fat free lean growth rate and $24^0 C$ ambient temperature, digestible energy intake (or feed intake) is the main factor used to simulate daily protein retention and daily body weight gain for pigs with particular body weights in the growth model. The simulation model tended to systematically over-estimate the average daily feed intake. The faster growth and higher nitrogen retention of simulated pigs as observed in Table IV-13 may be attributed to higher simulated daily digestible energy or feed intake. To best compare simulation results with experimental results of the daily protein retention and daily body weight gain, the actual values of feed intake from the swine experiments (digestible energy intake) were used in the simulation model to calculate the daily protein retention and daily body weight gain (DFADNR(2) and DFADG(2)). The differences between simulated and experimental ADNR and ADBWG calculated by using the actual digestible energy intake from the experiment as shown in Appendix Table A4-22 were used in the regression analysis.

Figure IV-4 and 4-5 shows that the experimental and simulated ADNR have similar trends. From Table IV-15, it can be seen that the simulation model significantly under-estimated the actual values of daily nitrogen retention in most of experiments for pigs fed the standard Corn-SBM diets at five percent level. In addition, the null hypothesis that interaction $\text{Diets} \times \text{Experiment}$ in all diets of the experiments had no effects on the difference between experimental and simulated ADNR was rejected by the data.

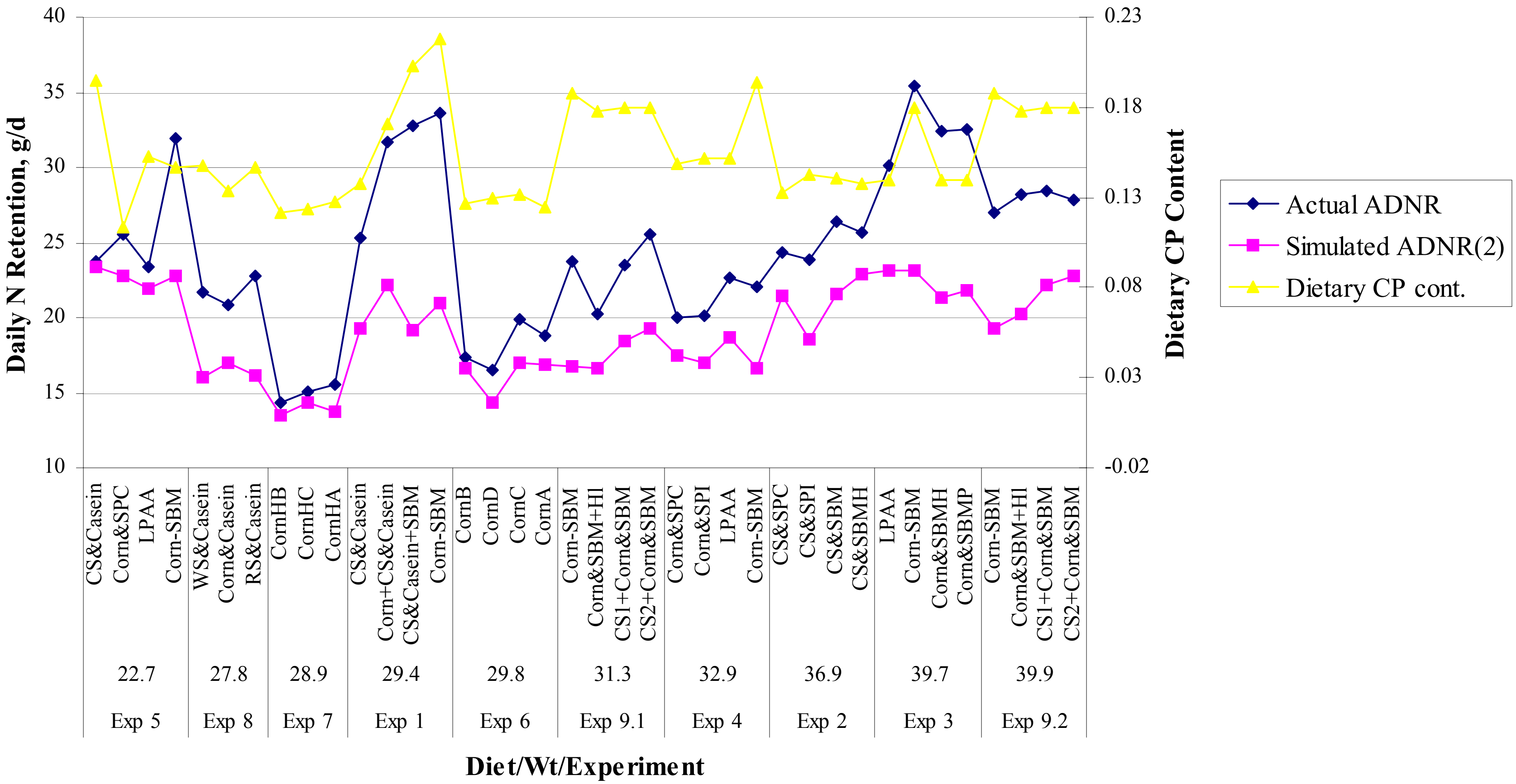

Figure IV-4. The relationship between experimental and simulated ADNR(2), and dietary CP content for different diets, sorted by animal body weight.

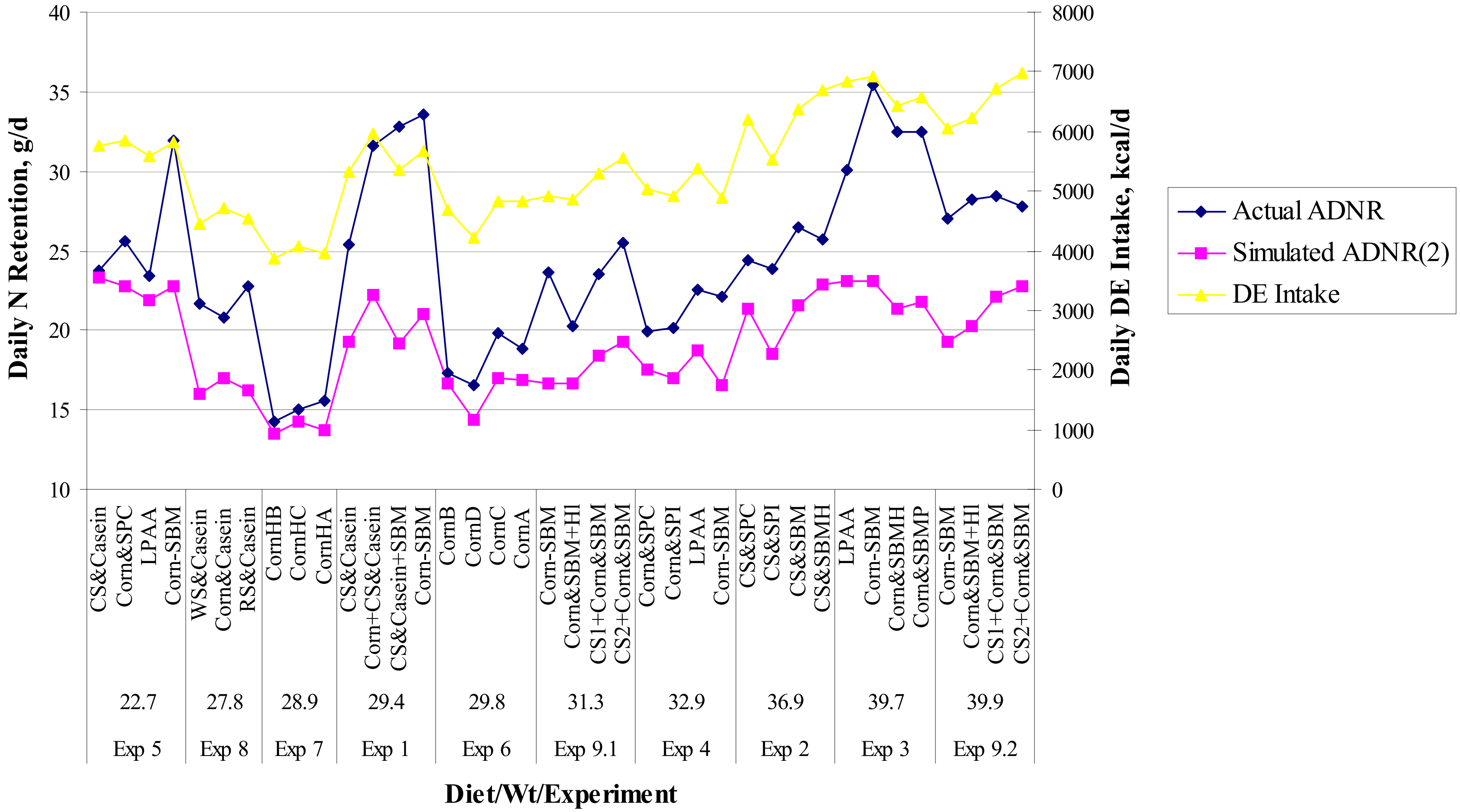

Figure IV-5. **The relationship between experimental and simulated ADNR(2), and daily DE intake for different diets, sorted by animal body weight.**

The amount by which the simulated model under-estimated the actual ADNR was significantly increased for pigs fed the diets of CS&Casein+SBM, and Corn+CS&Casein. The gap between experimental and simulated ADNR was smaller but still significant for pigs fed the diets of Corn&SPC, Corn&Casein, CS&Casein, Corn&SPI, CornA, CornC, CornD, CornHA, Corn&SBM+H1, LPAA, CS&SBM, CS&SBMH, CS&SPC, and CS&SPI. Similar to the simulated daily feed intake, the simulated daily nitrogen retention was calculated by animal body weight, and DE intake (equation 4-6). Since actual animal weights and DE intake were used in simulating pig daily nitrogen retention, variation in the difference between measured and simulated ADNR for different diets suggests that actual daily nitrogen retention may also be influenced by dietary nutrient content in addition to animal body weight. As pigs grow, the actual nitrogen retention moved up more than the simulated values, which may reflect the highly CP content in the diets of CS&Casein+SBM, and Corn+CS&Casein. The low CP content in the diets of Corn&SPC, CS&Casein, Corn&SPI, CornA, CornB, CornC, CornD, CornHA, CornHB, CornHC, CS&SBM, CS&SBMH, CS&SPC, and CS&SPC may be the reason why pigs fed those diets had significantly lower ADNR than those fed the typical corn&SBM diet.

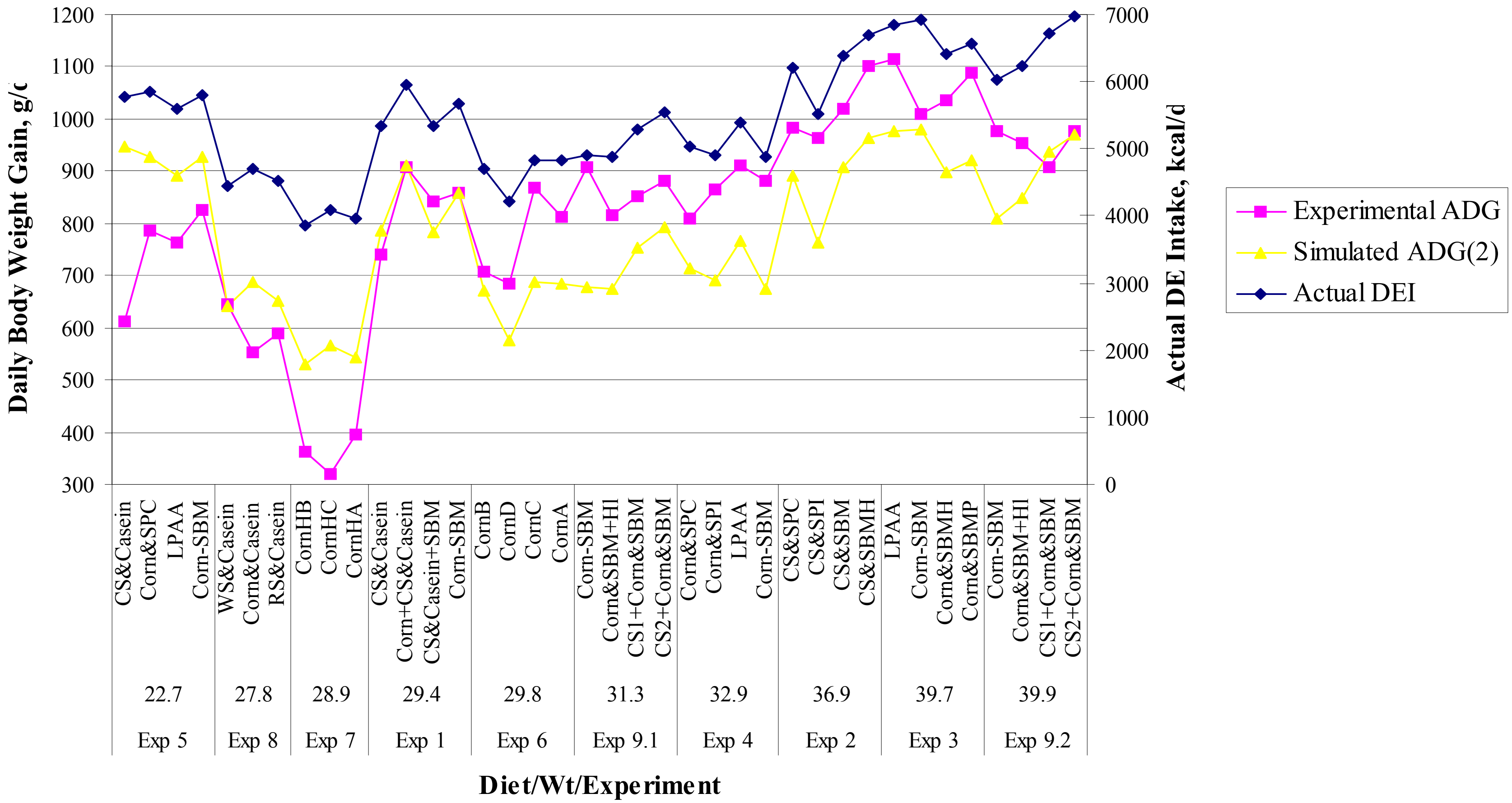

Figure IV-6. The relationship between experimental and simulated average daily body weight gain, ADG(2), in gram per day for different diets, sorted by animal body weight.

Experimental Vs Simulated Daily Body Weight Gain

The average daily body weight gain (ADBWG, grams per day) is the sum of daily protein tissue gain and daily fat tissue gain multiplied by a coefficient to account for the other parts of body weight gain, such as bone and skin. Moreover, the fat tissue gain increases as the energy surplus given to the animals increases in the NRC model. Therefore, daily protein retention and digestible energy intake are important factors in determining the daily body weight gain. The conversion coefficients of chemical and physical components of pig body recommended by the NRC (1998) were derived from numerous experiments and were considered to be consistent with the experimental data. In the present analysis, in which the simulated daily body weight gain was calculated by actual DE intake, the discrepancy in simulated and actual daily body weight gain may be attributed to miss-estimated values of daily protein retention. From Table IV-15, it can be seen that the simulated ADBWG was not significantly different from the actual values of daily body weight gain for pig fed the standard Corn-SBM diet at the one percent level, except for experiment 4 and 9. However, the null hypothesis that the interaction effect $\text{Diets} \times \text{Experiment}$ had no effect on the difference between experimental and simulated ADBWG was rejected by the data (p=0.0001). Figure IV-6 shows that the NRC simulation model overestimated animal daily body weight gain in the experiments 5, 8 and 7 with lower pig body weights, and under-estimated animal daily body weight gain in the experiments with higher pig body weight. Table IV-15 shows that the simulated ADBWG calculated by using actual DE intake was significantly higher than the experimental ADBWG for pigs fed the diets of CS&Casein, Corn&Casein, CornHA, CornHB, and CornHC, in which both actual ADNR and DE intake was low. The simulated ADBWG of the pigs fed the diets of CS&SPI, Corn&SBMP, and CornC associated with high measured ADNR and DE intake was significantly lower than the experimental ADBWG at five percent level.

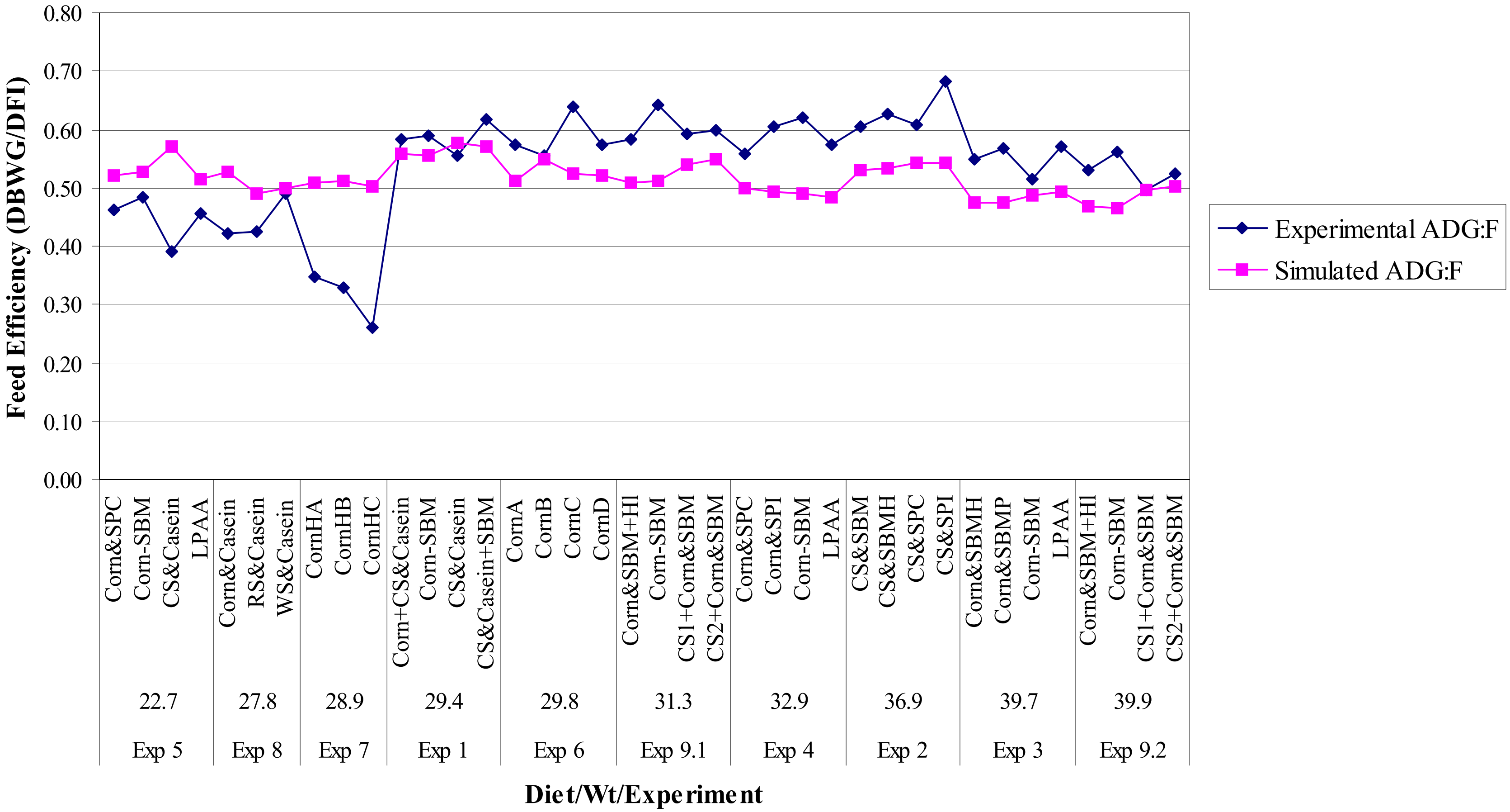

Figure IV-7. **The relationship between experimental and simulated feed efficiency for different diets, sorted by animal body weight.**

Experimental Vs Simulated Feed Efficiency

Differences in feed efficiency (ADGF) between experimental and simulated pigs are due to the differences in ADG and ADFI between simulated and trial pigs. Figure IV-7 shows that the NRC simulation model over-estimated animal daily body weight gain in the experiments with lower pig body weights, and under-estimated animal daily body weight gain in the experiments with higher pig body weights. From Table IV-15, the value of feed efficiency predicted by the simulation model was not significantly different from the experimental ones in the standard Corn-SBM diets, except for experiments 4, 9.1, and 9.2. The NRC simulation model significantly over-estimated experimental feed efficiency in the diets of CornC, Corn&SPI, CS&SBMH, CS&SPI, and Corn&SBMP. In the diets of Corn&Casein, CornHA, CornHB, and CornHC, in which simulated values of daily body weight gain was significantly greater than the measured ones, simulated feed conversion efficiency of pigs was also significantly higher than the experimental feed efficiency at five percent level. As shown in Table IV-15 and Figure IV-7, significantly lower experimental feed efficiency than the simulated feed efficiency was observed for pigs fed the diets of Corn&Casein, in which actual daily body weight gain was significantly lower than the simulated one at five percent level. For the diets of Corn HA, Corn HB, and Corn HC, in which both actual daily feed intake and body weight gain were significantly lower than the simulated ones, experimental feed conversion efficiency was significantly lower than the simulated values at one percent level. There was no significant difference between the simulated and experimental values of feed conversion efficiency for pigs fed other low crude protein, amino acids supplemented diets.

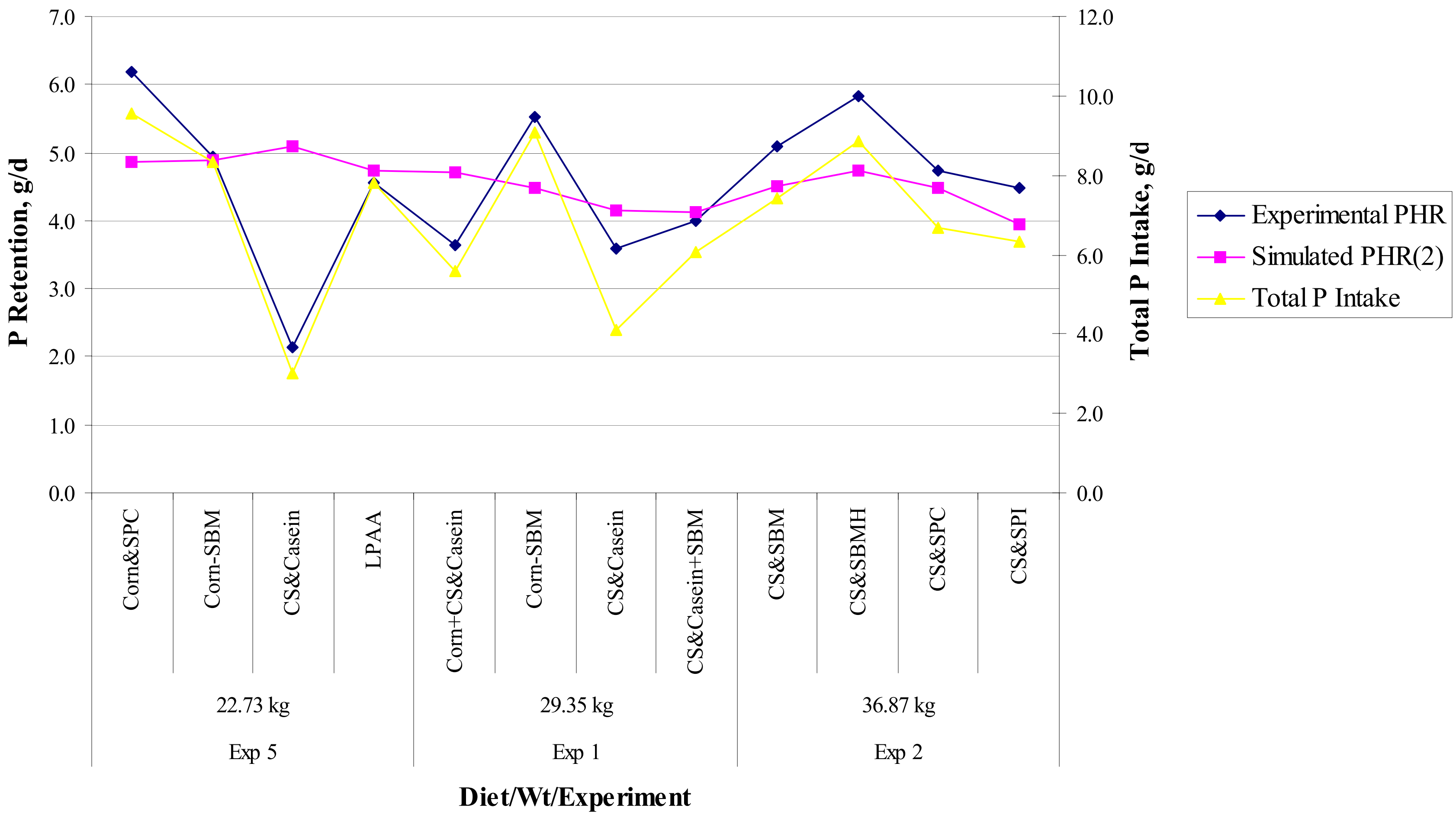

Figure IV-8. **The relationship between experimental and simulated phosphorus retention, PHR (2), and total P intake (gram per day) for different diets, sorted by animal body weight.**

Experimental Vs Simulated Daily Phosphorus Retention

For a pig with particular body weight, digestible energy intake (or feed intake) is the main factor determining daily phosphorus retention in the growth simulation model. The higher phosphorus retention of simulated pigs (PHR(1)) as observed in Table IV-14 may be attributed to higher simulated daily digestible energy or feed intake. To best compare simulation and experimental results of the daily phosphorus retention, experimental digestible energy intakes were used in the simulation model to calculate the daily phosphorus retention (PHR(2)). Figure IV-8 shows that after accounting for the effects of higher digestible energy intake, the actual daily phosphorus retention calculated by the measured digestible energy intakes (PHR(2)) was larger than the simulated phosphorus retention in most of the diets. Low phosphorus retention was observed for the diets of Corn+CS&Casein and CS&Casein with low total phosphorus contents. On the other hand, for the high total phosphorus concentration diets formulated with ingredients of low digestible P ingredients (the diet of CS&SBMH), phosphorus retention was higher. Though diet manipulation can reduce the phosphorus content in the diet and manure by including highly digestible feed ingredients, it may also have adverse effects on animal growth.

It can be concluded that the simulation model tended to systematically over-estimate the daily feed intake, and under-estimate daily body weight gain, nitrogen retention, and phosphorus requirements. The actual values of average daily body weight gain, nitrogen and phosphorus retention, feed intake, and feed conversion efficiency were all significantly different from the simulated values in some diets of the experiments. The results of hypothesis tests suggest that further adjustment on the NRC simulation model is necessary to improve its ability to predict pig daily protein and phosphorus retention, and DE intake.

Regression Analysis in the Nutritional Effects on Pig Growth

In the previous section, we found that the discrepancies between simulated and experimental growth variables significantly varied across diets of the low protein, low phosphorus feeding trials conducted by Carter *et al.* (1999; 2000; 2001; 2003). As the simulated values of growth variables was based on the animal initial body weight, the significant variation in the predictability of the NRC simulation model across dietary treatments suggested that the change in dietary composition or nutritional content in addition to pig physical stages is also important in determining animal growth. The following linear regression was therefore suggested to quantify the effect of dietary nutritional content on animal daily protein retention (g/d):

$$PR = \alpha + \beta_1 BW + \beta_2 CPT + \beta_3 DET + \beta_4 RANI + Littermate + \varepsilon, \qquad (4\text{-}14)$$

where PR is the animal daily protein retention (g/d). BW is animal body weight in kg. DET is the DE content in the diet, CPT is the CP content in the diet, and $\mathrm{RANI_d}$ is the ratio of nitrogen from total essential amino acid intake to the total nitrogen intake in a particular diet d. That is,

$$\mathrm{RANI_d} = \sum_{\mathrm{i=lys}}^{\mathrm{val}} \mathrm{EAAN_{di}}/\mathrm{TN_d} \qquad (4\text{-}15)$$

$\text{TEAA}_d = \sum_{i=lys}^{val} \text{EAAN}_{di}$ is the nitrogen content of total essential amino acids in the diet d. Table IV-15 gives the nitrogen content of each essential amino acid. TN_d is the total nitrogen content of the diet d.

Table IV-16. The Nitrogen Portion of Each Essential Amino Acid.

	Lys	Arg	His	Ile	Leu	Met	TSAA	Phe	P+T[a]	Thr	Try	Val
N_i	0.19	0.32	0.27	0.11	0.11	0.09	0.10	0.09	0.08	0.12	0.14	0.12

Source: Tom Brody, 1999.
[a] P+T=Phenylalanine+tyrosine.

A similar linear regression equation was used to estimate the effect of animal body weight, dietary DE and CP content, and the nitrogen content of total essential amino acids in the diet on DE intake. That is,

$$DEI = \alpha + \beta_1 IBW + \beta_2 CPT + \beta_3 DET + \beta_4 RANI + Littermate + \varepsilon, \qquad (4\text{-}16)$$

Regression analyses were carried out using the SAS PROC MIXED (SAS Inc., Cary, NC). The result of statistical analysis in the effect of dietary treatments on the growth variable across different dietary treatment and experiments was shown below.

$$PR = -128.5 + 2.2IBW + 636.9CPT + 10.1DET + 145.6RANI,$$

$$DEI = -2901.3 + 92.9IBW + 3374.5CPT + 1164.4DET + 812.3RANI.$$

Both protein retention and DE intake was significantly affected by animal initial body weight as expected ($p<0.0001$). The daily protein retention significantly increased with increasing dietary CP content ($p<0.0001$), and increasing nitrogen content of total essential amino acids in the diet ($p<0.0001$). However, the dietary DE content did not influence daily protein retention at five percent significance level ($p=0.43$). The daily DE intake in kcal per day significantly increased with the increase in dietary DE content at one percent level (p=0.0003). Both the dietary CP content (p=0.14) and dietary nitrogen content of total essential amino acids (p=0.33) did not significantly affect daily DE intake at five percent level.

Re-estimation of Daily DE Intake, N and P Retention

The evidence from analysis on experimental data shows the values of average daily feed intake and daily nitrogen retention predicted by NRC model are found to be significantly different than the measured values of experimental trials conducted by Carter *et al*. at Oklahoma State University. In addition, some of the functions presented in the NRC simulation model contain conversion coefficients of chemical and physical components, and parameters of nutritional requirements, which are less sensitive to the nutrient contents in the diets. The deductive and flexible nature of the body protein retention and voluntary DE intake equation in predicting animal growth, in contrast, make it more variable as the nutrient contents in the diets change. Thus, the parameters of the maximum DE intake equation and the whole body protein generating equation will be re-estimated.

The variation in the predictability of NRC simulation model may be attributed to three possible reasons. First, the coefficients of the NRC model may not adequately measure the growth functions and nutrient requirements. Second, growth variables may be affected by dietary treatments. Third, the NRC simulation model is intended to be used on the farm where pigs are normally fed for market, which may not be applicable to the data from pigs in a laboratory well-controlled metabolism chambers. Under farm conditions, there usually are 40 to 100 pigs in a single pen and the pigs are free to move around. As such, measurements taken from pens of pigs under commercial growing conditions are not the same measurements one would expect to get from animals in confined spaces under experimental conditions. It is necessary to adjust experimental data to reflect farm level uncontrolled conditions.

Statistical Calibration of the NRC DE Intake for Lab Condition

The original simulation model systematically over-estimates the daily digestible energy intake. The experimental values of maximum digestible energy intake are the amount of average daily feed intake multiplied by the estimated DE contents in diet. As actual digestibility energy contents of ingredients in the experiment may be different than those reported in NRC Feedstuff table, the difference in the parameters of DE intake equation between estimated values with experimental data and NRC published values may reflect the inaccurate determination of energy content of diets as well as unfitting parameters of maximum DE intake equation themselves. The more specific parameters of maximum digestibility energy intake could be obtained by more accurate determination of energy content in diets.

To predict the amount of digestible energy intake by pigs that weigh from 15 to 110 kg for ad lib feeding conditions, a linear regression model based on Eq (3-1) (National Research Council, 1987; Agricultural Research Council, 1981) was developed. The framework for this regression model with classical assumptions is as follows:

$$\mathbf{DEI}_d = \beta_1 \times [1 - \exp(\beta_2 \mathbf{BW}_d)] + \boldsymbol{\varepsilon}_d, \qquad d = 1, \ldots\ldots\ldots, D \qquad (4\text{-}13)$$

where $\boldsymbol{\varepsilon} = [\boldsymbol{\varepsilon}_1', \boldsymbol{\varepsilon}_2', \ldots, \boldsymbol{\varepsilon}_D']'$, and $E[\boldsymbol{\varepsilon}\boldsymbol{\varepsilon}'] = \sigma^2 \mathbf{I}_D$.

The regression equation was in an exponential functional form with voluntary DE intake as dependent variable, and body weight as the explanatory variables. For the present, we assume that the parameter vector β_i is the same for all d. In the experimental data, the live weights of growing pigs were limited, ranging between 14.9 and 58.7 kg. The data with limited range of body weight are not suitable for re-estimation of the parameter associated with body weight during the whole growing period. Therefore, β_2 in the DE intake equation was fixed at –0.0176 as what the NRC recommended.

To compare actual voluntary DE intake with predicted voluntary DE intake by equation (4-1) above, we first estimate the parameter β_1 by using only the data on corn-soybean meal diet in the experiments. Corn is the primary energy-supplying ingredient in diets for swine in the United States. Soybean meal is usually the most economical source of protein. Since the Corn-SBM diet is the most common ration in practical swine feeding operations, one can assume the NRC model is also based on the industry standard Corn-Soybean Meal (Corn-SBM) diet. A new intercept that represents the effect of controlled growth chamber conditions was obtained from nonlinear ordinary least squares estimator by stacking the data on Corn-Soybean Meal diet in the pooled regression model (Equation 4-13).

$$\begin{aligned}&\text{Maximum DE Intake (MxDEI, kcal/day)}\\&= \underset{(340.0)}{12133} \times (1 - e^{-0.0176 BW_t})\end{aligned} \qquad (4\text{-}14)$$

The estimated standard error was shown in the parentheses. Hypothesis test was conducted to determine whether the intercept (12,133) estimated by the experimental data on the Corn-SBM diet was significantly different than the intercept recommended by NRC (13,162). The null hypothesis is

$H_0 : \beta_1 = 13162.$

From the SAS output, Wald statistic = 9.16 with p-value = 0.0025 for corn-SBM diet. This is larger than the critical values at the one percent significance level. So the NRC intercept value was rejected in favor of the re-estimated for corn-SBM diet data. Since all the experimental data come from animals housed individually in metabolism chambers, while the NRC simulation model is based on the farm where pigs are fed under commercial conditions, the difference between the NRC predictions for farm and those observed in the experiment for the corn soybean diets may be attributed to the difference between the farm and the laboratory. The significantly lower intercept of the DE intake equation under the experimental condition reflected that pigs housed individually in metabolism chambers had lower DE intake than those on the farm where pigs are free to move.

There are a large number of cross-sectional units (dietary treatments) and only a few pig replicates in the experimental data set. A model better suited to these short and wide data sets would take cross-sectional variation or heterogeneity into consideration. A more general model would allow the variance to differ between experiments and consider correlation between littermates, and α to vary across dietary treatments. In this case, the equations are linked only by their disturbances, and analysis could be conducted with a seemingly unrelated regression model.

For the experiments characterized by the longitudinal data, a plausible assumption is that parameters vary across dietary treatments (i.e., across the cross-sectional units). However, if dietary treatments have no effect on growth variables, the same intercepts should enter all of the equations across the cross-sectional units, and the set of equations has cross-equation restrictions. Considerable efficiency will be gained by estimating the equations jointly; otherwise estimating the equations separately will waste the information that the same set of parameters appears in all of the equations. On the other hand, if growth variables were affected by dietary treatments, the model should apply to grouped data rather than a full data set.

To determine whether the intercept was the same for all dietary treatments, a null hypothesis that the intercept for all low nitrogen, low phosphorus dietary treatments are not different from 12,133 was tested to investigate the dietary treatment effects. Equation (4-15) shows the estimation of the intercept by pooling all observations and estimating the coefficients by ordinary least squares.

$$\begin{aligned}&\text{Maximum DE Intake (MxDEI, kcal/day)}\\&= \underset{(119.7)}{11909.23} \times (1 - e^{-0.0176BW_t})\end{aligned} \qquad (4\text{-}15)$$

The estimated standard error is shown in the parentheses. From the SAS output, Wald = 3.50 with p-value<0.0612. This is larger than the critical values for the ten percent significance level. The null hypothesis that $H_0 : \beta_1 = 12133.$ was thus rejected. The difference between the intercept estimation for Corn-SBM diet and for all diets in the experiments may demonstrate the influence of dietary treatments. In addition, the *p*-value of Type 3 tests for the fixed effect and the results of regression analysis in the Table IV-15 suggest that dietary treatment significantly affected pig DE intake. Figure IV-6 shows that after adjusting for animal body weight, daily DE intakes were higher for pigs fed the diets of Corn+CS&Casein and CS&SBMH with DE content of 3.83 and 3.81 kcal per gram of feed than those fed the diets of CornA, CornB, CornC, and CornD with much lower DE content. There was a similar response of daily DE intake to crude protein content in the diets. Daily DE intake was higher for pigs fed the standard Corn&SBM diets with 22 percent CP in the experiment 5 than those with heavier body weight but fed low CP diets of LPAA, RS&Casein, WS&Casein, and Corn HA, Corn HB, and Corn HC in experiment 5, 8 and 7. Pigs fed the low DE and CP content diets had DE intake that was lower than those of pigs fed the standard corn-SBM diet.

Estimated DE Intake for Various Diets under Lab Condition

A more general model would allow parameters to differ across dietary treatments; i.e. β_1 to vary across dietary treatments with different nutritional content. Differences in nutrient composition of the diets were compared using a model that included DE and CP content in the diet as independent variables. Bellego *et al*. (2001) reported that available energy for body growth increased as dietary protein was reduced. The ratio of nitrogen from total essential amino acid intake to total dietary nitrogen was therefore included in the regression model. This was done to determine whether a lack of total dietary nitrogen or non-essential amino acids might contribute to differences in DE intakes. As daily feed intake or DE intake was considered not to depend on pig genotypes (NRC, 1998), empirical analyses were made by using the SAS Model Procedure (SAS Inst. Inc., Cary, NC) with the following regression model:

$$\begin{aligned}\mathbf{DEI}_{\mathrm{d}} = EXP(&\beta_{1n}\mathbf{RANI}_d + \beta_{2n}\mathbf{RANI}_d^2 + \beta_{nd}\mathbf{RANI}_d \times \mathbf{DET}_d \\ &+ \beta_{1d}\mathbf{DET}_d + \beta_{2d}\mathbf{DET}_d^2) \times 12133[1 - \exp(-0.0176\mathbf{BW}_{\mathrm{d}})] + \boldsymbol{\varepsilon}_{\mathrm{d}},\end{aligned} \tag{4-16}$$

where $\mathbf{DET}_{\mathrm{d}}$ is the DE content in the diets, and $\mathbf{RANI}_{\mathrm{d}}$ is the ratio of N from total essential amino acids to total dietary N in a particular diet i. That is,

$$\mathrm{RANI}_{\mathrm{d}} = \sum_{\mathrm{i=lys}}^{\mathrm{val}} \mathrm{EAAN}_{\mathrm{di}} / \mathrm{TN}_{\mathrm{d}} \tag{4-17}$$

For ad lib feeding conditions, voluntary DE intake was predicted by the following asymptotic regression from experimental data on 26 dietary treatments:

$$\begin{aligned}\mathbf{DEI}_{\mathrm{d}} &= EXP(-17.8\mathbf{RANI}_d + 11.5\mathbf{RANI}_d^2 + 1.8\mathbf{RANI}_d \times \mathbf{DET}_d \\ &\quad + 2.2\mathbf{DET}_d - 0.4\mathbf{DET}_d^2) \times 12133[1 - \exp(-0.0176\mathbf{BW}_{\mathrm{d}})],\end{aligned} \tag{4-18}$$

To test whether voluntary DE intake was dependent on the DE or CP content in the diet as reported by Bailleul *et al*. (2001), the following joint and separate tests were performed:

$$H_0\colon \beta_{1n} = 0,\ \beta_{2n} = 0,\ \beta_{1d} = 0,\ \beta_{2d} = 0,\ and\ \beta_{nd} = 0. \tag{4-19}$$

$$\begin{aligned}&H'_{01}\colon\beta_{1n} = 0,\ H'_{02}\colon \beta_{2n} = 0,\ H'_{03}\colon\beta_{1d} = 0, \\ &H'_{04}\colon \beta_{2d} = 0,\ and\ H'_{05}\colon \beta_{nd} = 0\ .\end{aligned} \tag{4-20}$$

For jointly testing the hypothesis that all $\beta_{1.}$ are indifferent from the NRC values in the nonlinear model, the Wald test was carried out. The SAS output shows the Wald statistic is 122.54 with p-value<0.0001. This is much smaller than the critical values for the one percent significance level. The null hypothesis that DE content and N content of total essential amino acids in the diet had no effect on DE intake was thus jointly rejected in favor of the DE intake equation with the adjustment term. For separate hypothesis tests that each $\beta_{1.}$ is not significantly from the NRC value of the voluntary DE intake equation, the Wald test was again performed to test whether each null hypothesis in equation (4-20) is true. The SAS output shows all statistics for separate tests were smaller than the critical values at the five percent significance level. The hypotheses that the overall and separate effect of DE content and EAAN/TN in the diet had no influence on voluntary DE intake equation were rejected. In fact, the DE intake for ad lib feeding conditions varied across different experiments, although all diets in each experiment were formulated to be isocaloric and to meet the nutritional requirements.

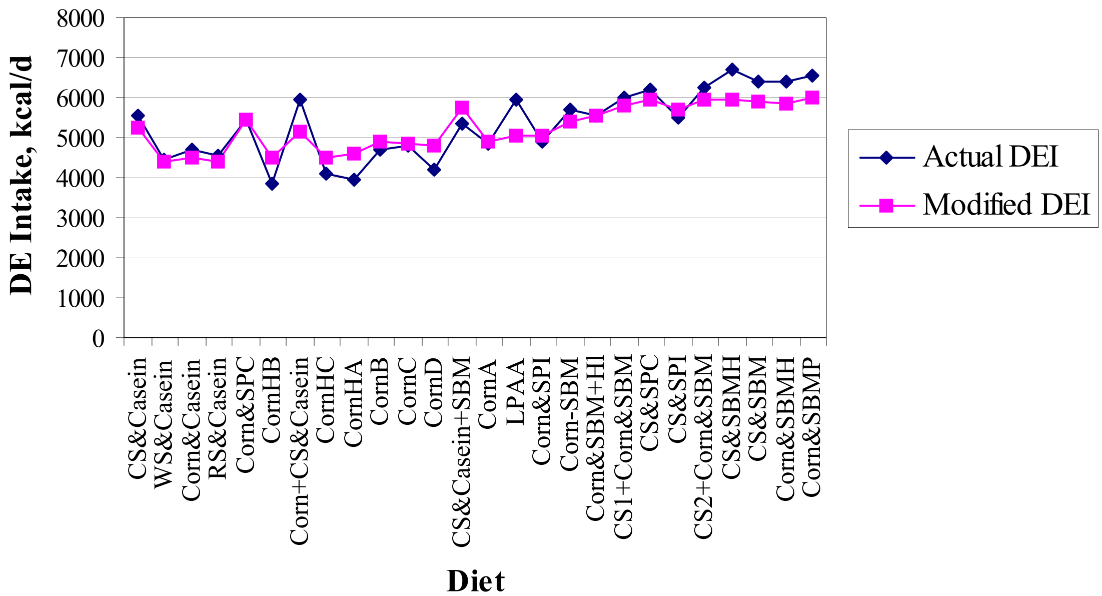

Figure IV-9. Daily DE Intake (kcal/day): the actually values vs. the estimated values with modified DE intake equations, sorted by the animal body weight.

The voluntary DE intake predicted by equation (4-18) matched the actual ones very well, except for the diets of Corn+CS&Casein, Corn HA, Corn HB, Corn HC, and LPAA, as shown in Figure IV-9. Pigs adjust DE intake according to their body weight as well as dietary DE and CP concentration, represented by the ratio of $TEAAI_d/CPI_d$. Since the calculated values of DE, EAA, and CP contents were used in the regression and simulation analysis, the discrepancy in actual values of DE intake and those predicted by DE intake equation may simply reflect measurement errors. In addition, the DE and nutrient contents of some feed ingredient, such as soy hull or Casein, may be under-estimated. The under-estimated DE intake for the diets of CS-SBMH, and Corn+CS&Casein could be attributed to the under-estimated nutrient content and amino acid digestibility of soybean hull and casein.

Statistical Calibration of the Protein Retention for Lab Condition

To re-estimate the parameters of the body protein retention equation, a nonlinear mixed model with the same functional form as the equation (3-3) will be fit, with daily body protein retention (PR_t) being the dependent variable, and average body weight and DE intake above 55 percent of requirements for maintenance being the fixed effect variables. The data concerning the amounts of protein retention and other performance variables of growing pigs were presented in the form of average values during the collection period. Average body weights used in the regression analysis were calculated by final and initial body weight for the collection period. In addition, the values of variable, digestible energy intake, are the amount of average daily feed intake multiplied by the DE contents in diets.

Since only one value of ambient temperature ($24^0 C$) was available in the data of experiments conducted by Carter *et al.*, statistical analysis was not possible for the effects of thermal conditions on whole body protein accretion rate. The ambient temperature in the whole body protein generating equation was set to be $24^0 C$ for all experiments. The dependent variable in the regression, daily body protein retention (PR), is not available in the experimental data, but can be converted from the average daily nitrogen retention by multiplying DNR with a coefficient, 6.25. That is,

$$\text{Protein Retention (PR, g/day)} = 6.25 \times \text{Daily Nitrogen Retention.} \qquad (4\text{-}21)$$

The data set from Carter et al. that contains series of growth and nutrient intake variables observed in certain feeding period combine numerous replicates and cross sections. The number of cross-sectional units is relatively large and the number of replicates is relatively small for the data observed across dietary treatments. These panel, or longitudinal data sets are wide, short, and more oriented toward cross-section analyses.

The data set used in the regression analysis consists of D cross-sectional units (dietary treatments), denoted $d = 1, \ldots\ldots, D$, with R_d pig replicates, $r = 1, \ldots\ldots, R_d$. The total observations are $\sum_{d=1}^{D}\sum_{r=1}^{R_d} r$. To relate pig genotype (generally expressed as mean lean growth rate during the feeding period) to its whole body protein accretion rate, the mean fat-free carcass lean accretion rate (MFFL) will enter the model as a random effect variable linearly. MFFL was specified to follow a normal distribution with mean of 350 gram per day, and a constant variance σ_{ur}^2 that is heteroscedastic across pig of different littermates. That is,

$$\mathrm{MFFL_r} \sim \mathrm{iid\ N}(350,\ \sigma_{ur}^2),$$

Under the assumption that the mean fat-free carcass lean accretion rate ($\mathrm{MFFL_r}$) follows a normal distribution with mean 350, and variance σ_{ur}^2, the conditional distribution for the response variable, $\mathrm{PR_d}$, given the random effects is then:

$$\mathrm{PR_d} \sim \mathrm{iid\,N}((\beta_1 e^{\beta_2 \mathrm{BW_d}} + \beta_3) \times \beta_4 \times 350 \times \beta_5 \times \mathrm{ADE_d}, \sigma_{\mathrm{ed}}^2),$$

where β_1, β_2, β_3, β_4, and β_5 are the fixed-effects parameters.

The pig body weights in the data set that were analyzed in the NRC model ranged from 20 to 120 kg. Applicability and accuracy decreases, if the parameters associated with body weight β_1, and β_2 are re-estimated with experimental data conducted at Oklahoma State University, in which the live weights of growing pigs were limitedly ranged between 14.88 and 58.69 kg. The data with limited range of body weight are not suitable for re-estimation of the coefficient associated with body weight in the protein retention equation during the whole growing period. In addition, since only pigs with the genotype of high lean-gain potential were used, and all the experiments were conducted under constant thermal conditions, the data are impossible to fit a single equation with the effect of animal genotypes and ambient temperature for all the pigs. The parameters of model affected by the initial body weight, genotypes and thermal condition will be fixed at the same levels as those NRC recommended. A regression model for calculating daily PR during the growing-finishing period from initial body weight, mean carcass fat-free lean gain during that period, and DE intake above 55 percent of maintenance was then set up as follows:

$$\begin{aligned}\mathbf{PR}_d &= h(\mathbf{BW}_d, \mathbf{MFFL}_d, \mathbf{DEA}_d, \alpha_d) + \boldsymbol{\varepsilon}_d \\ &= (17.5\,e^{-0.0192\mathbf{BW}_d} + \alpha) \times 0.003137\mathbf{MFFL}_d \times 0.94\mathbf{DEA}_d + \boldsymbol{\varepsilon}_d, \quad d = 1, \ldots\ldots, D\end{aligned} \tag{4-22}$$

$$E[\varepsilon_{dr}] = 0,$$

$$Var[\varepsilon_{dr}] = \sigma_r^2,$$

$$Cov[\varepsilon_{dr}, \varepsilon_{fr}] = 0,$$

where each cross-sectional vector, $\mathbf{BW}_d$, $\mathbf{MFFL}_d$, and $\mathbf{DEA}_d$ has R_d observations, and $\mathbf{DEA}_d$ is actual digestible energy intake (DE) above 55 percent of maintenance, expressed in grams per Mcal. Due to the correlated random effect for pigs of same littermates, disturbance terms are correlated across dietary treatments. The intercept will be re-estimated using the experimental data of Carter *et al*. (1999; 2000; 2001; 2003). That is, the nonlinear mixed model specifies that

$$\mathbf{PR}_t = (17.5e^{-0.0192\mathbf{BW}_d} + \alpha) \times 0.003137\mathbf{MFFL}_t \times 0.94\mathbf{DEA}_t + \boldsymbol{\varepsilon}_t, \tag{4-23}$$

As described previously, the NRC simulation model is intended to be used on the farm where pigs are free to move around. As one would expect, daily protein retention from animals in metabolism chamber under experimental conditions was usually higher. To adjust the farm level uncontrolled parameters to reflect laboratory confined space condition with the experimental data, we first estimate the parameter α by using only the data on corn-soybean meal diet in the experiments. A new intercept that represents the effect of controlled growth chamber conditions may be obtained from the ordinary least squares estimator of the pooled regression model above based on the data on Corn-Soybean Meal diet. The difference between the intercept term predicted by NRC for farm and observed in the experiment for the corn soybean diets is assumed to represent the difference between the farm and the laboratory conditions. Equation (4-24) shows the estimated value of the intercept the protein retention equation above with the data on the Corn-SBM diet.

$$\mathbf{PR}_d = (17.5e^{-0.0192\mathbf{BW}_d} + \underset{(0.6822)}{27.52}) \times 0.003137\mathbf{MFFL}_d \times 0.94\mathbf{DEA}_d \tag{4-24}$$

The estimated standard error is shown in the parentheses. A hypothesis test was conducted to determine whether the intercept (27.52) estimated by ML estimators for Corn-SBM diet was significantly different than the NRC intercept (16.25). For hypothesis testing and confidence intervals in a nonlinear regression model, the usual procedures can be used, with the proviso that all results are only asymptotic (Green, 1991). The test of whether the NRC prediction for farm is different than that observed in the experiment for the corn soybean diets was carried out by imposing the constraints of the hypothesis on estimators. That is,

$H_0 : \alpha = 16.25.$

For testing the hypothesis that α is indifferent from the NRC prediction in the nonlinear model, an asymptotic F test, based on the approximate chi-squared distributions, is carried out. From the SAS output, F=273.09 with p-value<0.0001 for corn-SBM diet. This is larger than the critical values at the one percent significance level. The significantly higher estimated intercept value than that recommended by NRC for farms suggested that protein retention for pigs housed individually in metabolism chambers tends to be higher than pigs fed under commercial conditions.

Protein Retention for Various Diets under Lab Condition

Previous studies have shown decreased excretion of N with decrease dietary crude protein content, but with sufficient essential amino acid content in the diet (Ganh et al 1998a; Misselbrook et al, 1998). To determine whether there is effect of dietary crude protein content on protein retention, it is necessary to ascertain the influence of dietary treatments on the intercept estimated. Since all the experiments were conducted under laboratory conditions, a null hypothesis that the intercept for the low nitrogen, low phosphorus dietary treatments are not different from 27.52 was tested to investigate the dietary treatment effects. The intercept of the equation (4-23) was re-estimated with experimental data on diets other than the Corn-SBM diets. Equation (4-25) shows the estimation of the intercept by using data sets on all diets except Corn-SBM diet.

$$\mathbf{PR}_d = (17.5 e^{-0.0192\mathbf{BW}_d} + \underset{(0.3117)}{22.42}) \times 0.003137\mathbf{MFFL}_d \times 0.94\mathbf{DEA}_d \tag{4-25}$$

The estimated standard error is shown in the parentheses. Hypotheses tests were conducted to determine whether the intercept estimated for all diets except Corn-SBM diet was different than that estimated for Corn-SBM diet, 27.52. The test of whether the intercept estimated for all diets in the experiments except Corn-SBM diet is different than that estimated for the Corn-SBM diets was carried out by imposing the constraints of the hypothesis on estimators. That is,

$H_0 : \alpha = 27.52.$

The asymptotic F test, based on the approximate chi-squared distributions, is carried out to test the hypothesis that α for all diets except Corn-SBM diets is indifferent than the estimated value for the industry standard Corn-SBM in the regression model. From the SAS output, F=267.44 with p-value<0.0001. This is larger than the critical values for the one percent significance level. The null hypothesis that the intercept value estimated for all diet except Corn-SBM diet is indifferent than the estimation for Corn-SBM diet was thus rejected. The difference between the intercept estimation for Corn-SBM diet and for all diets except Corn-SBM diet in the experiments may demonstrate the influence of dietary treatments. In addition, the *p*-value of Type 3 tests for the fixed effect conducted in the previous section was significant at one percent level. The hypotheses that the overall fixed effect and each dietary treatment variable, and treatment$\times$experiments interaction had no influence on the predictability of the simulation model for the daily nitrogen retention were rejected. In fact, the performance of the simulation model in predicting the ability values of variables varied across various diets, although all diets were formulated to satisfy the nutritional requirements.

As such, the identification of the dietary treatment affects call for alternative parameter vector estimation that allows intercepts to vary across dietary treatments. To identify the effect of each low CP diet on pig protein retention, a regression model was formulated by assuming that differences across dietary treatments can be captured in differences in the intercept terms between a particular diet and Corn-SBM diet. That is,

$$\mathbf{PR}_d = (17.5e^{-0.0192\mathbf{BW}_d} + 27.52 + \beta_i D_i) \times 0.003137\mathbf{MFFL}_d \times 0.94\mathbf{DEA}_d + \boldsymbol{\varepsilon}_d, \quad (4\text{-}26)$$

where D_i is a dummy variable, equal to one if the observation is from the *i*th dietary treatment and zero otherwise. Because of this, the model above is usually referred to as *the least squares dummy variable* (LSDV) model.

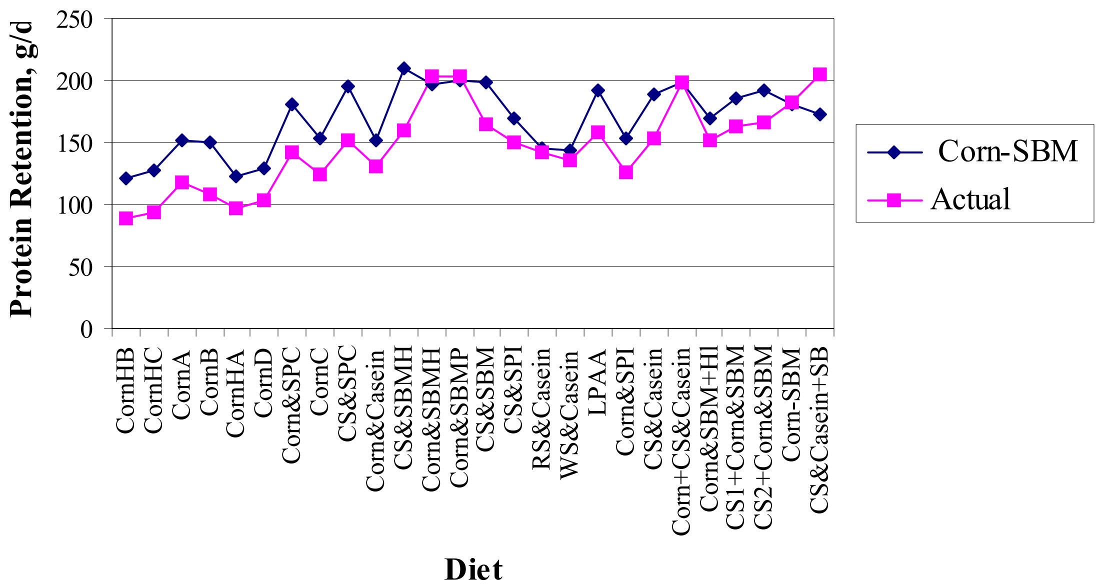

Figure IV-10**.** The effects of dietary manipulations on daily protein retention, sorted by dietary CP content.

Pigs fed the corn-SBM diet had different average DE intakes for the overall experimental period than pigs fed the low-protein, amino acid-supplemented diet. As the level of feed intake increased (decreased), there was a concomitant increase (decrease) in protein retention and daily body weight gain for pigs fed a low-protein, amino acid-supplemented diet. Therefore, the greater or lower protein retention of the pigs fed the corn-SBM diet than the pigs fed a low protein, amino acid-supplemented diet may be due to the difference in DE intake rather than the dietary effects. The experimental data did not report the animal DE intake. To take the effect of feed intake on the growth performance of pigs into account, the actual digestible energy intake was calculated by multiplying the amount of actual daily feed intake from the experimental data by the DE contents for each diet. The actual digestible energy intakes calculated for each diet was then substituted in the protein retention equation of the corn-SBM diet to estimate daily protein retention.

The estimated parameters of dummy variable represented the difference between the simulated protein retention if pigs fed the standard Corn-SBM diet and actual protein retention for a particular low CP diet. Since actual body weight and DE intake of each individual pig were used to calculate the simulated protein retention of the Corn-SBM diet, the estimated parameters represent only the dietary effects, and are not correlated with animal body weight.

The transformed data for daily protein retention consist of series of four to six replicate observations for each of 26 diets. The initial experimental data from 9 experiments and 26 dietary treatments were grouped by diets. Dummy variables were used to test if the intercept for protein retention in the ith diet was significantly different from 27.52. Least squares estimation of the model with individual diet dummy variables is shown in Table IV-16 (PROC MIXED, SAS).

Table IV-17. The estimated difference between corn-SBM and other diets in the intercepts of the simulation protein retention equation.

D_i [a]	α			Diff in protein ret[c]
	Estimate	DF	t-Value	
CornHB	-9.7611***	232	-11.28	-92.433
CornHC	-10.0698***	232	-10.33	-87.961
CornA	-8.4113***	232	7.90	-63.946
CornB	-10.3137***	232	10.18	-73.554
CornHA	-8.0624***	232	-8.25	-85.094
CornD	-7.7272***	232	-6.88	-78.879
Corn&SPC	-7.1914***	232	9.18	-35.886
CornC	-7.1147***	232	6.44	-57.852
CS&SPC	-7.8702***	232	7.76	-29.121
Corn&Casein	-5.9653***	232	-6.65	-53.365
CS&SBMH	-8.3249***	232	8.52	-20.710
Corn&SBMH	1.0714	232	0.83	20.951
CS&SBM	-6.0535***	232	5.73	-17.223
CS&SPI	-4.4037***	232	3.88	-33.259
RS&Casein	-1.0812	232	-1.11	-40.399
WS&Casein	-2.0674*	232	-2.06	-45.967
LPAA	-6.0739***	232	9.56	-21.397
Corn&SPI	-6.6858***	232	6.07	-55.812
CS&Casein	-6.4818***	232	8.05	-24.380
Corn+CS&Casein	-0.3657	232	0.26	15.403
Corn&SBM+Hl	-3.3593**	232	-3.72	-28.623
CS1+Corn&SBM	-4.3743***	232	-5.01	-18.884
CS2+Corn&SBM	-4.8191***	232	-5.64	-14.961
Corn&SBMP	0.2397	232	0.19	20.843
Corn-SBM	--[b]	--	--	--
CS&Casein+SBM	7.4903***	232	4.31	25.691

The probability of a significant treatment effect are indicated by * P<0.05, ** P<0.01, *** P<0.001.

[a] Diets were sorted by dietary CP content.

[b] The estimated intercept term for the Corn-SBM diet was included as the constant term for comparison.

[c] Diff protein ret (gram/day) = the daily protein retention of pigs fed a particular diet – the daily protein retention of pigs fed the equivalent Corn-SBM diet.

Estimating the model with dietary treatments denoted by dummy variables provides us an opportunity to observe the effects of diet manipulations on swine daily protein retention in contrast to the industry standard Corn-SBM diet. The coefficients on each dummy variable can be interpreted as the difference in the intercept term of the daily protein retention equation between a particular diet and the Corn-SBM diet due to different nutrient content across dietary treatments. The calculated daily protein retentions from the growth model developed from the *Nutrient Requirements of Swine* (NRC, 1998) for each manipulated diet were then compared against the results for the Corn-SBM diets. The intercept term for the typical corn&SBM diet estimated in the previous section was 27.52 units. The data from the Table IV-16 show the estimated intercept values of daily protein retention equation for the diets of CS&Casein, CS&SBM, CS&SBMH, CS&SPC, CS&SPI, LPAA, Corn&SPC, Corn&SPI, CornA, CornB, CornC, CornD, CornHA, CornHB, CornHC, Corn&Caesin, CS1+Corn&SBM, CS2+Corn&SBM, and Corn&SBM+H1 were all significantly smaller ($p<0.01$) than the estimated values for the Corn-SBM diet. The estimated intercept values of the daily protein retention equation for the diets of Corn+CS&Casein, RS&Casein, and WS&Casein were not significantly different than estimated values for the Corn&SBM diet. The estimated intercept value of the protein retention equation for the dietary treatments with fiber, Corn&SBMH and Corn&SBMP were insignificantly larger than the estimate intercept values for the standard Corn-SBM diet. Only for the diet of CS&Casein+SBM, the estimate intercept value of the protein retention equation was significantly larger than the intercept value estimated by the data on the Corn-SBM diet.

Diets formulated with the concept of optimal dietary pattern among essential amino acids offer a flexible means of selecting available feed ingredients to meet the nutrient requirements of pigs. Since the requirement for each amino acid can be calculated from a single amino acid, such as lysine, it also provides an effective and economical way to formulate low-protein, amino acid-supplemented diets so as to reduce nitrogen excretion from pig production. However, experiments in which the Corn-SBM diets and manipulated diets with ideal protein patterns have been compared have given inconsistent results. Gomez *et al*. (2002) has reported pigs fed ideal protein diets have lower growth performance than the pigs fed the Corn-SBM diets. Shriver *et al*. (2003) reported little or no difference in daily nitrogen retention and body weight gain between pigs fed the Corn-SBM and ideal protein diets. In our study, the higher predicted values of protein retention with simulation equation estimated by the data of Corn-SBM diet suggest that pigs fed with the Corn-SBM diet had significantly higher total protein retention than those fed with the low crude protein, amino acid supplemented diets. To identify possible reasons for the discrepancies observed in the intercept terms of the protein retention equation when pigs had been fed a manipulated diet vs. the alternative and equivalent Corn-SBM diet, we first estimated the requirement profile of essential amino acids for the industry standard Corn-SBM diet. Essential amino acid and crude protein contents of a particular diet were then compared against the requirements based on the standard Corn-SBM diet to determine possibilities that caused the low protein retention of pigs fed the low crude protein, amino acid supplemented diets.

The intercept of the protein retention equation for the standard Corn-SBM diet increased from 16.25 to 27.52 when it was adjusted to pass through the mean of protein retention of the pigs fed the Corn-SBM diet in the experiments. The protein retention for experimental pigs fed fortified corn-soybean meal diet tended to be greater than the values estimated for the farm pigs of the NRC model. However, the Corn-SBM diet in the experiments had similar essential amino acid contents than the Corn-SBM diet formulated with Nark's recommendation. Since protein retention for experimental pigs fed fortified corn-soybean meal diet tended to be greater, and their amino acid intakes did not increased, pigs in the laboratory consequently utilized amino acid more efficiently for protein retention. Increases in the amino acid efficiency for protein retentions resulted in a decrease in lysine requirement for a given daily whole-body protein retention. Moreover, the live weights of growing pigs used in the experiments were limitedly ranged between 14.9 and 58.7 kg. To avoid of reduction in the applicability and accuracy of the NRC model, in which the analysis in refers to pigs with body weights ranged from 20 to 120 kg, the parameters associated with body weight in the lysine requirement equation will not be re-estimated. Therefore, the equation for true ilea digestible lysine requirement (Telis) that will be re-estimated using the experimental data on the Corn-SBM diets is as follows:

$$\begin{aligned}&\text{Total Digestible Lysine Requirement (TDLys, g/day)}\\&= \text{Lysine req. for Maintenance} + \text{Lysine req. for Protein Retention}\\&= 0.036 \times BW_t^{0.75} + \beta_1 \times PR_t\end{aligned} \qquad (4\text{-}27)$$

The true ilea digestible lysine required consists of that required for maintenance and those for protein deposition. The modified models, re-estimated with the experimental data, generated the nutrient requirements. The estimated protein retention was obtained by substituting the calculated digestible energy intakes in the modified protein retention equation. The digestible energy intakes were calculated by multiplying the amount of average daily feed intake from the experimental data by the DE contents in diets. The true ileal digestible lysine requirement is estimated by the estimated protein retention with the calculated lysine intake on a true ileal digestible basis. Equation (4-24) shows the estimation of daily true ileal digestible lysine requirement by using the experimental data on Corn-SBM diet.

$$\begin{aligned}&\text{Total Digestible Lysine Requirement (TDLys, g/day)}\\&= 0.036 \times BW_t^{0.75} + \underset{(0.0026)}{0.076969} \times PR_t\end{aligned} \qquad (4\text{-}28)$$

The estimated standard error is shown in the parentheses. The parameter for protein retention in the digestible lysine equation, $\hat{\beta}_1 = 0.076969$. Hypotheses tests were conducted to determine whether the parameters of total digestible lysine requirement estimated using the data from the Corn-SBM diet in the experiment were significantly different than the NRC parameter, 0.12. The Wald, LR, LM test was carried out. From the SAS output, Wald=344.04 with p-value<0.0001, LR=344.04 with p-value<0.0001, and LM=31.02 with p-value<0.0001 for β_1. This is larger than the critical values at the one percent significance level. Therefore, the null hypothesis that the re-estimated parameter is not different than NRC value (0.036) was rejected with the experimental data on the Corn-SBM diet. The parameter values for protein retention suggested by NRC were thus rejected in favor of the re-estimation. The results indicate that in these experiments the proportion of lysine above maintenance requirements was significantly lower than that expected from the NRC equation.

The requirements of the essential amino acids other than lysine for protein deposition can be calculated using the ideal protein system in which requirements for each of the other amino acids are expressed relative to the lysine requirement for protein accretion. That is, multiplying the estimated lysine requirement by the ideal protein system obtains the requirements for all other essential amino acids. Figure IV-11 shows the actual EAA profile and the estimated EAA requirement profile for the corn-SBM diet.

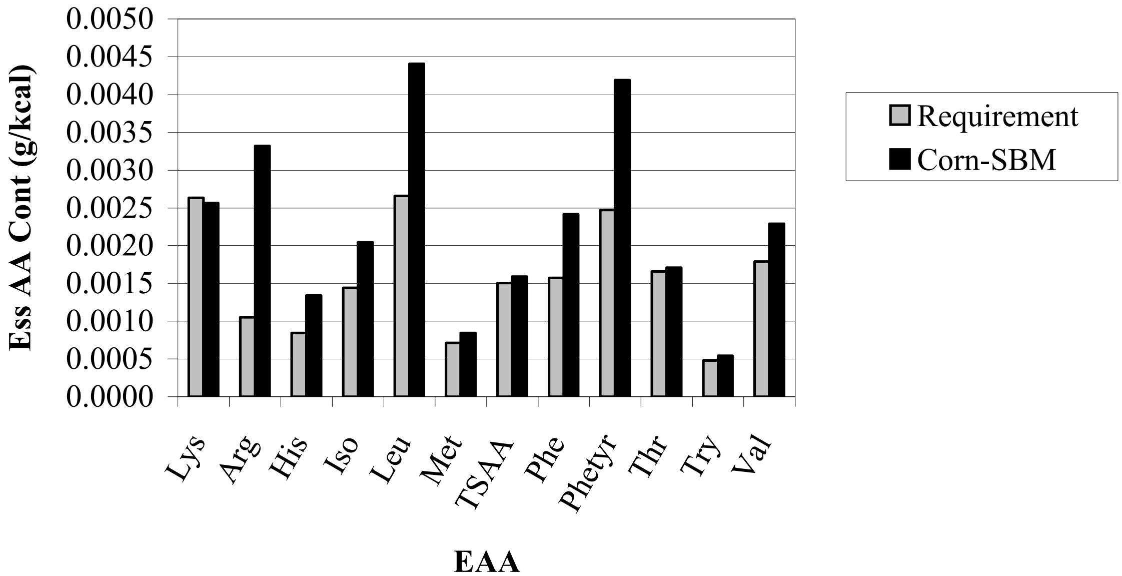

Figure IV-11. The actual essential amino acid profile and the essential amino acid requirement profile for the Corn&SBM diet for barrows weighing 32.62 kg.

To achieve the same protein retention as the pig fed the corn-SBM diets, the true ileal digestible lysine contributed by the low crude protein, amino acids supplemented diets must not be less than the requirement for the corn-SBM diets given the digestible energy concentration in diets. One must also be sure that the requirements for all the other essential amino acids will be adequate and that the amount of nonessential amino acid will be met as the Corn-SBM diets.

The initial experimental data were categorized into three groups by the results of regression results above. The first group includes the low protein, amino acid supplemented diets of CS&Casein, CS&SBM, CS&SBMH, CS&SPC, CS&SPI, LPAA, Corn&SPC, Corn&SPI, CornA, CornB, CornC, CornD, CornHA, CornHB, CornHC, Corn&Casein, CS1+Corn&SBM, CS2+Corn&SBM, and Corn&SBM+H1 that failed to produce the same high rates of protein retention that can be achieved by the pigs fed the typical corn-SBM diets. As shown on Table IV-16, all the dietary treatments in this data group had significantly lower protein retention levels than the equivalent Corn-SBM diets. The second diet group two included five diets (Corn+CS&Casein, RS&Casein, WS&Casein, Corn&SBMH and Corn&SBMP) for which the experimental protein retention was not significantly different from the standard Corn-SBM diet. The third dietary group consisted of a single diet, CS&Casein+SBM that resulted in significantly higher protein retention than the standard Corn-SBM diet.

The reduced in growth performance in growing and finishing pigs fed manipulated diets with ideal protein pattern as observed in the first dietary group are consistent with the results that have been reported in some experiments, in which lower performance levels were observed for pigs fed the diets with dietary CP reduced by more than 4 percent from 18 percent level (Smith *et al*., 1997; Gomex *et al*., 2002). There are several possibilities for this result. One explanation for differences in protein retention between the low crude protein, amino acid supplemented diets and the standard Corn-SBM diets is that the manipulated diets contained lower essential amino acid levels than the standard Corn-SBM diet.

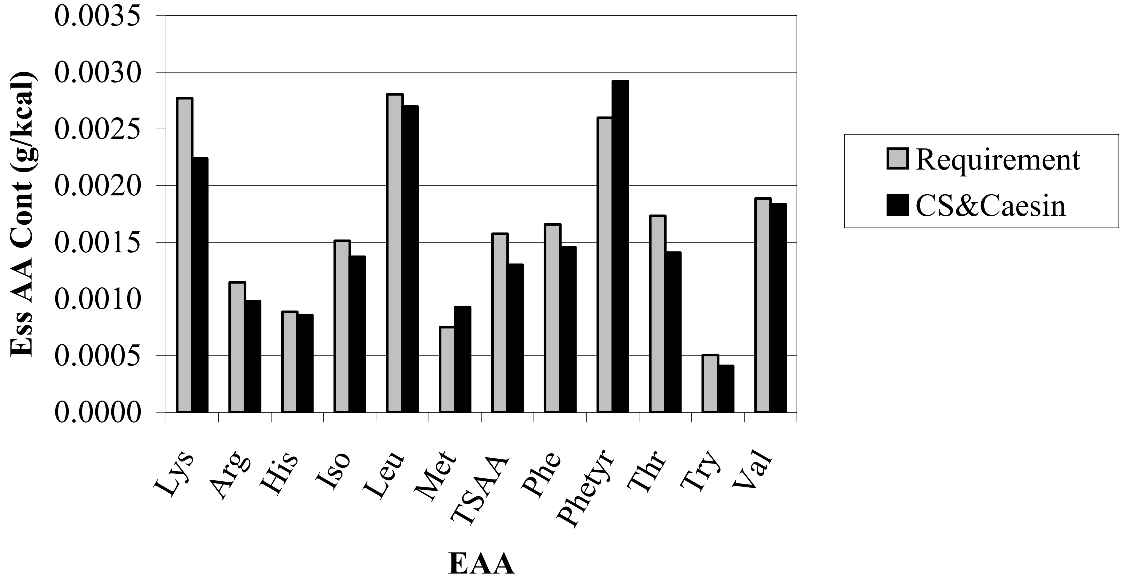

Figure IV-12. The actual essential amino acid profile of the CS&Casein diet vs. the EAA requirement profile.

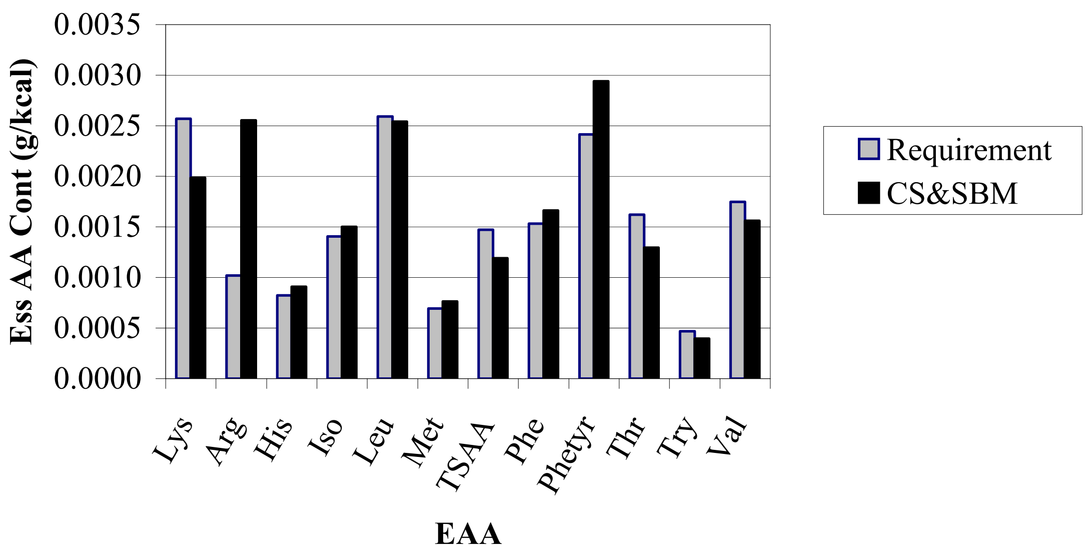

Figure IV-13. The actual essential amino acid profile of the CS&SBM diet vs. the EAA requirement profile.

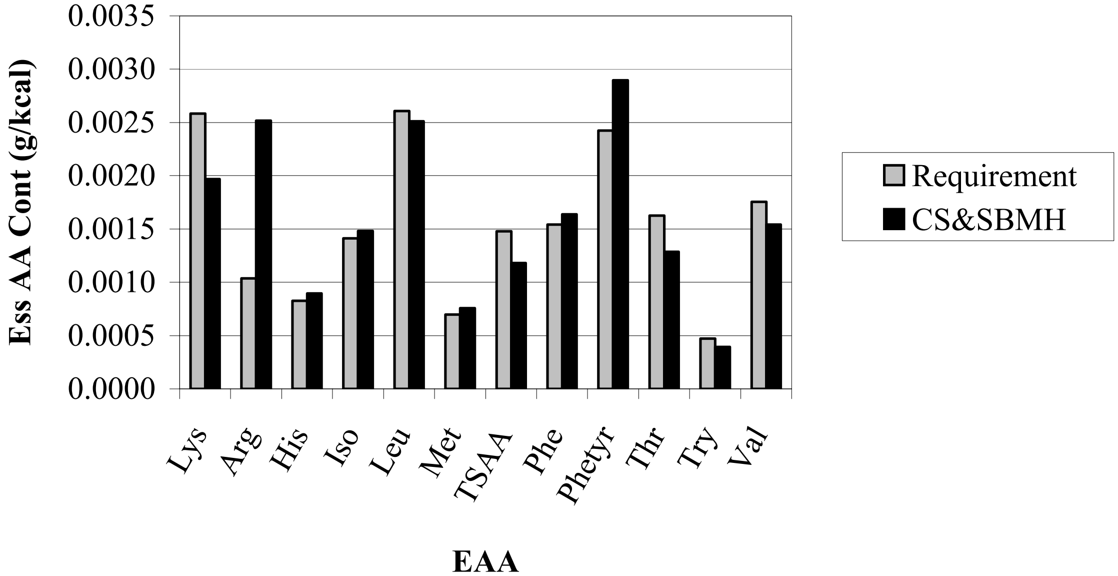

Figure IV-14. The actual essential amino acid profile of the CS&SBMH diet vs. the EAA requirement profile.

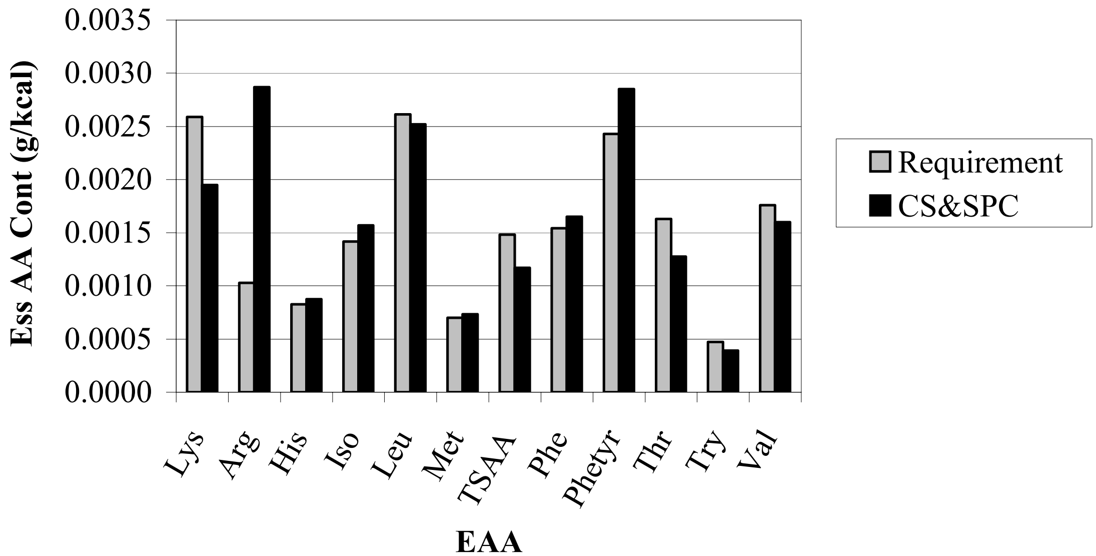

Figure IV-15. The actual essential amino acid profile of the CS&SPC diet vs. the EAA requirement profile.

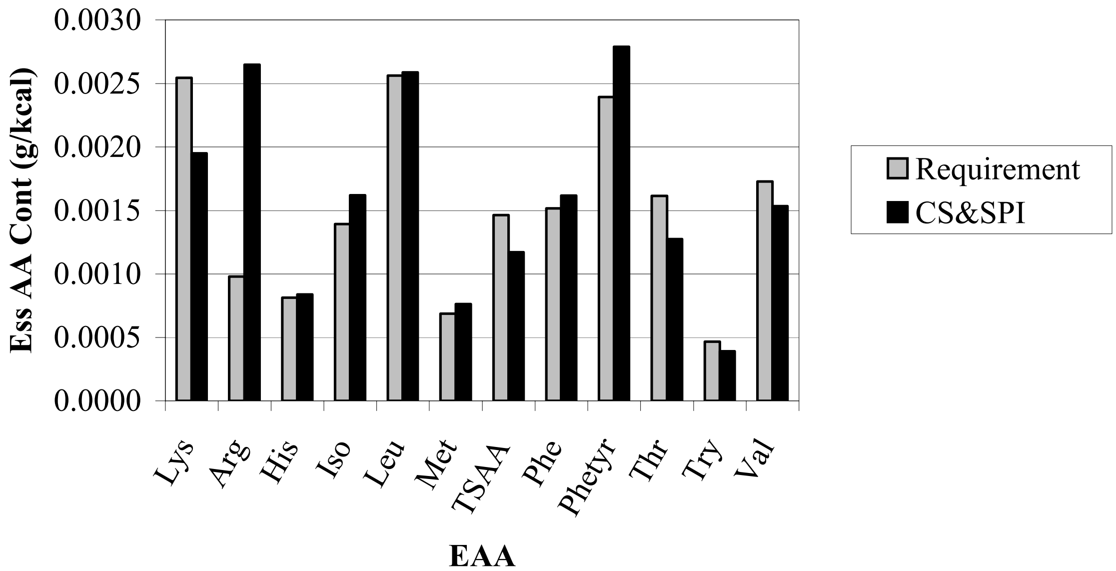

Figure IV-16. The actual essential amino acid profile of the CS&SPI diet vs. the EAA requirement profile.

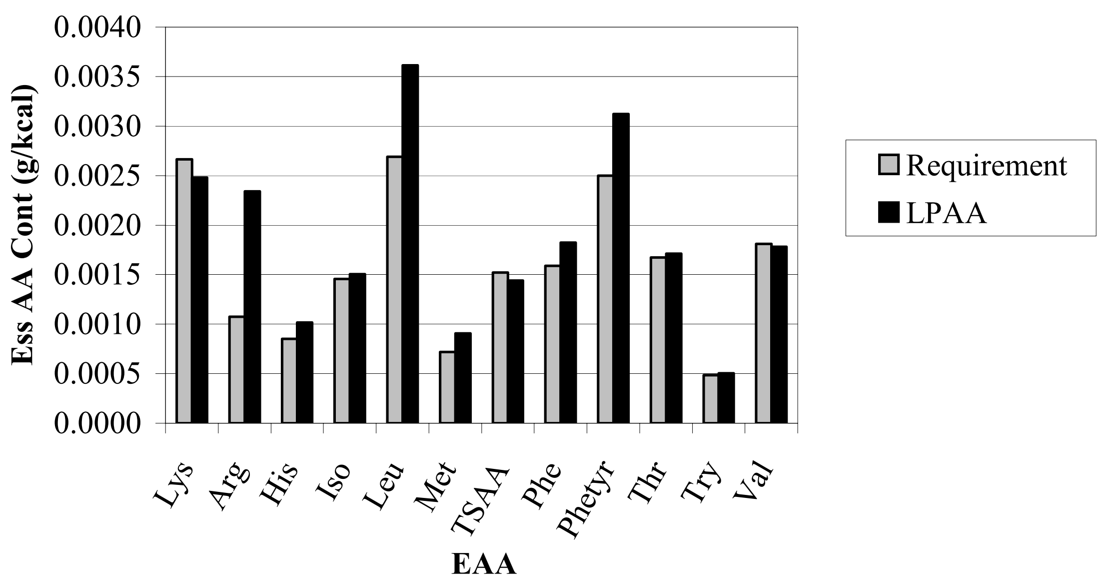

Figure IV-17. The actual essential amino acid profile of the LPAA diet vs. the EAA requirement profile.

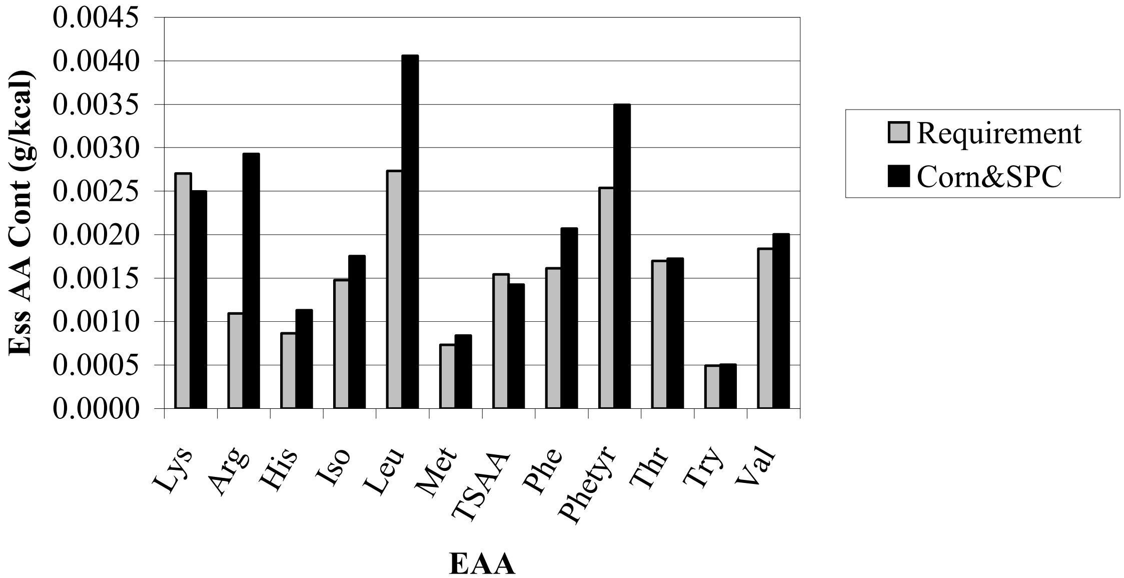

Figure IV-18. The actual essential amino acid profile of the Corn&SPC diet vs. the EAA requirement profile.

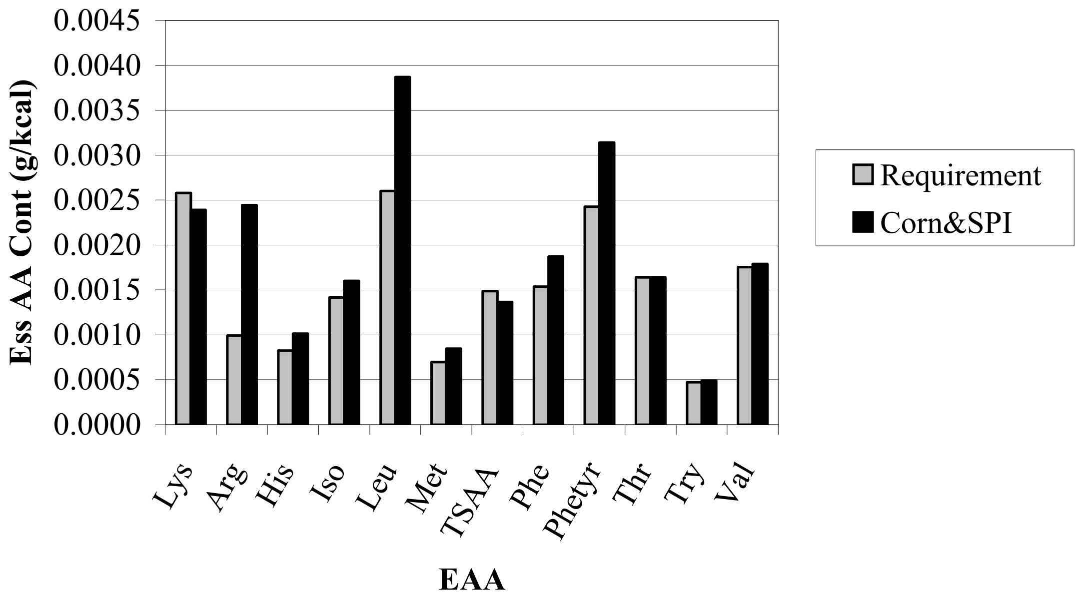

Figure IV-19. The actual essential amino acid profile of the Corn&SPI diet vs. the EAA requirement profile.

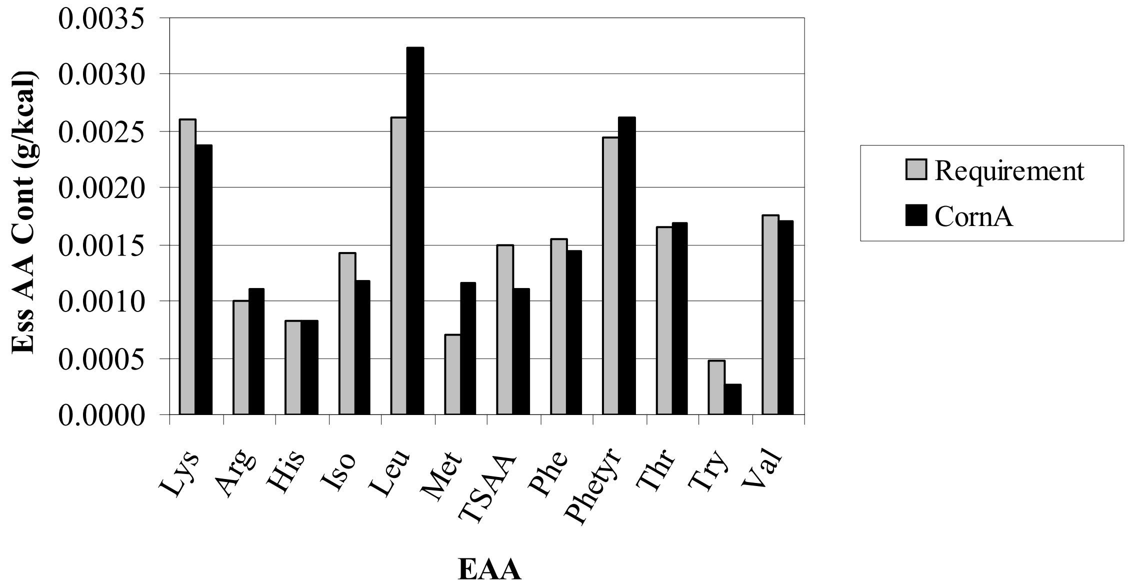

Figure IV-20. The actual essential amino acid profile of the CornA diet vs. the EAA requirement profile.

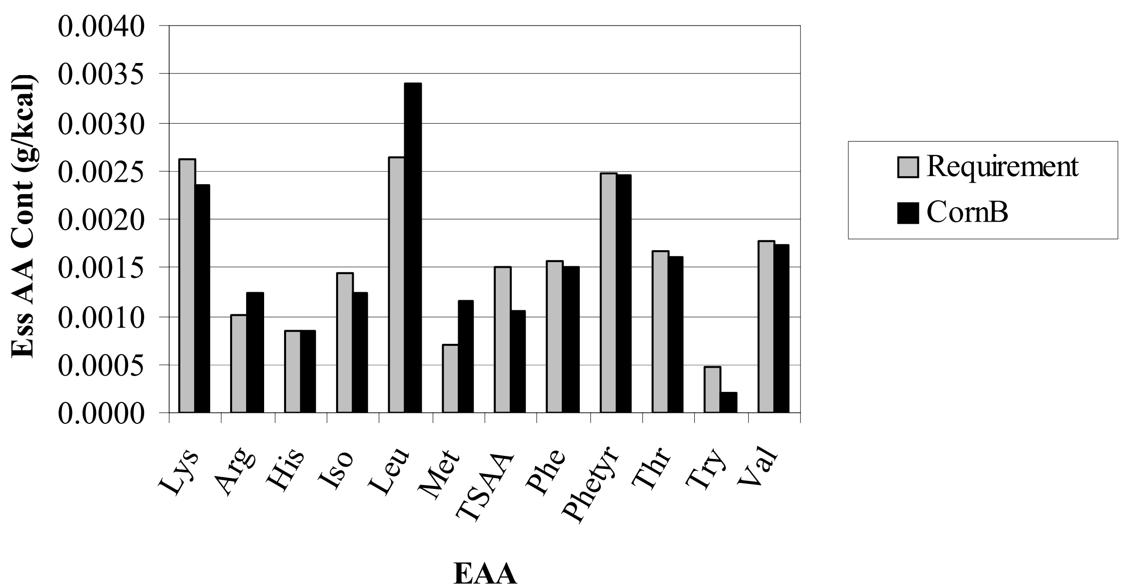

Figure IV-21. The actual essential amino acid profile of the Corn B diet vs. the EAA requirement profile.

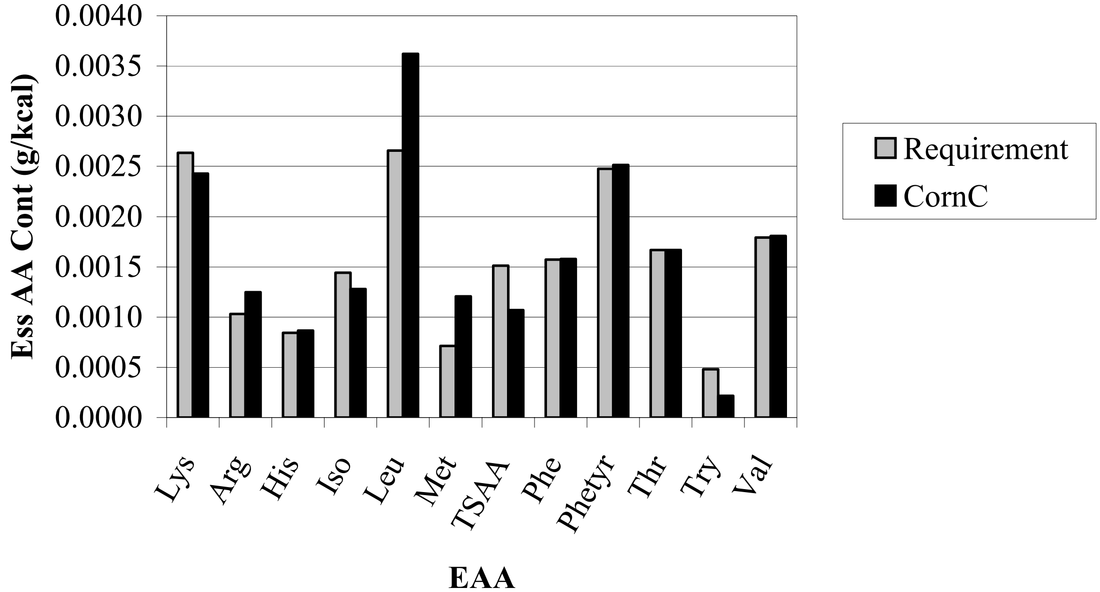

Figure IV-22. The actual essential amino acid profile of the Corn C diet vs. the EAA requirement profile.

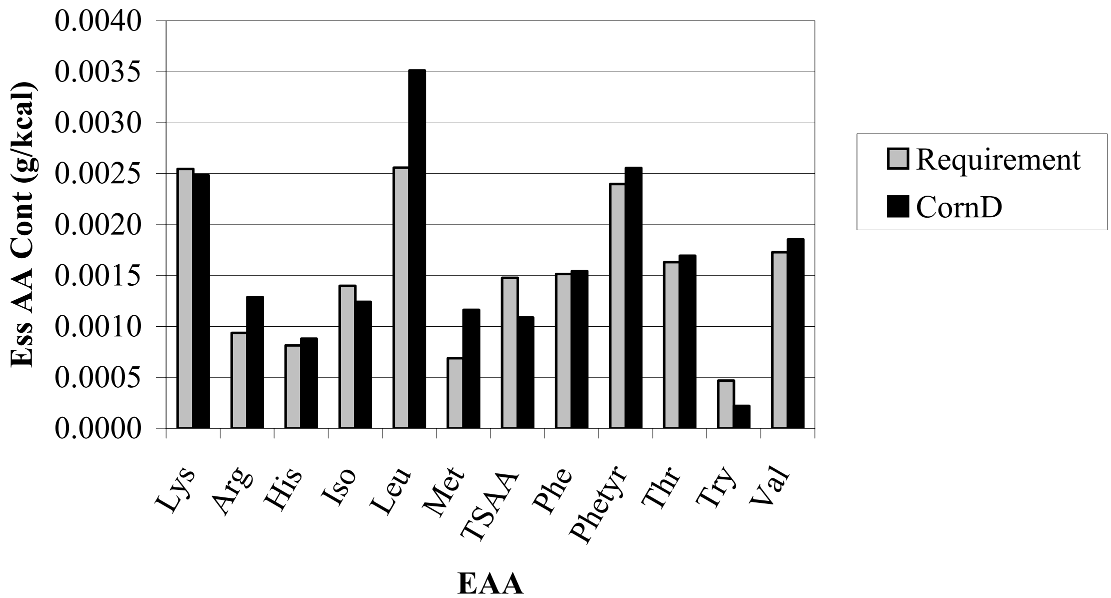

Figure IV-23. The actual essential amino acid profile of the Corn D diet vs. the EAA requirement profile.

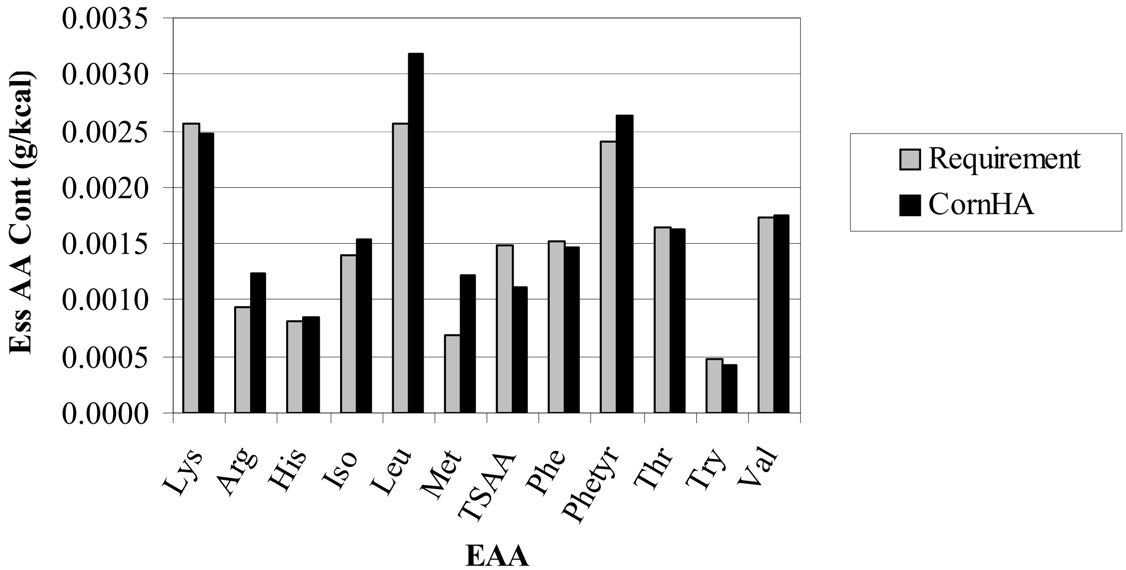

Figure IV-24. The actual essential amino acid profile of the Corn HA diet vs. the EAA requirement profile.

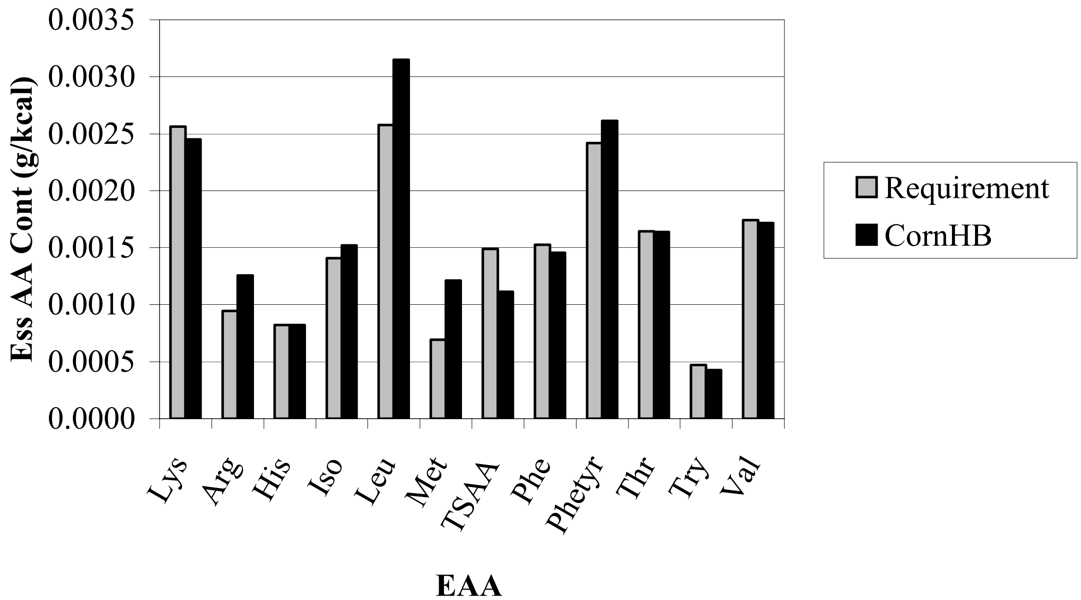

Figure IV-25. The actual essential amino acid profile of the Corn HB diet vs. the EAA requirement profile.

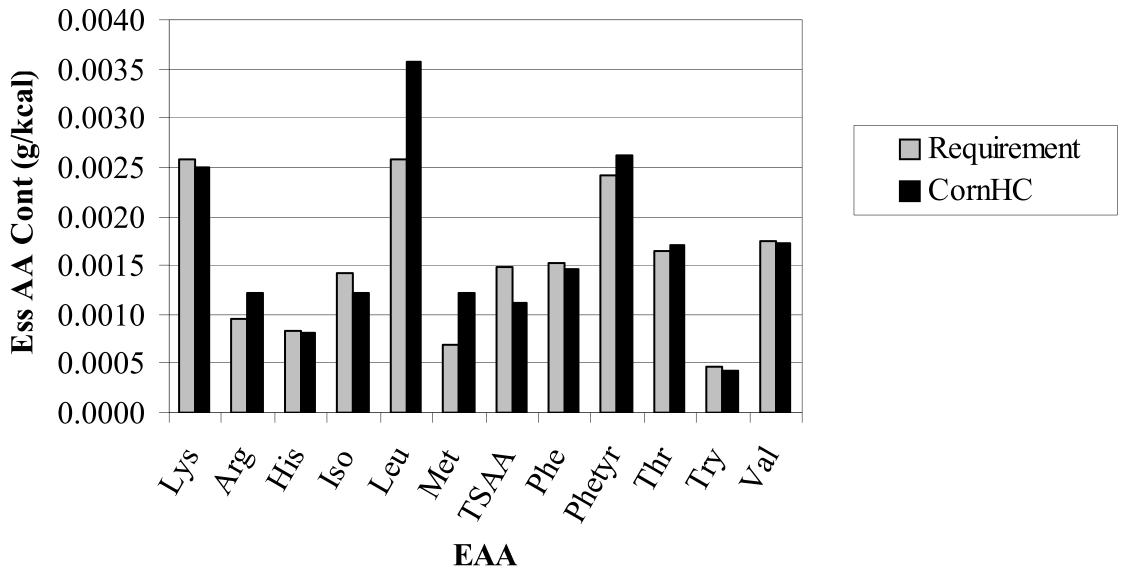

Figure IV-26. The actual essential amino acid profile of the Corn HC diet vs. the EAA requirement profile.

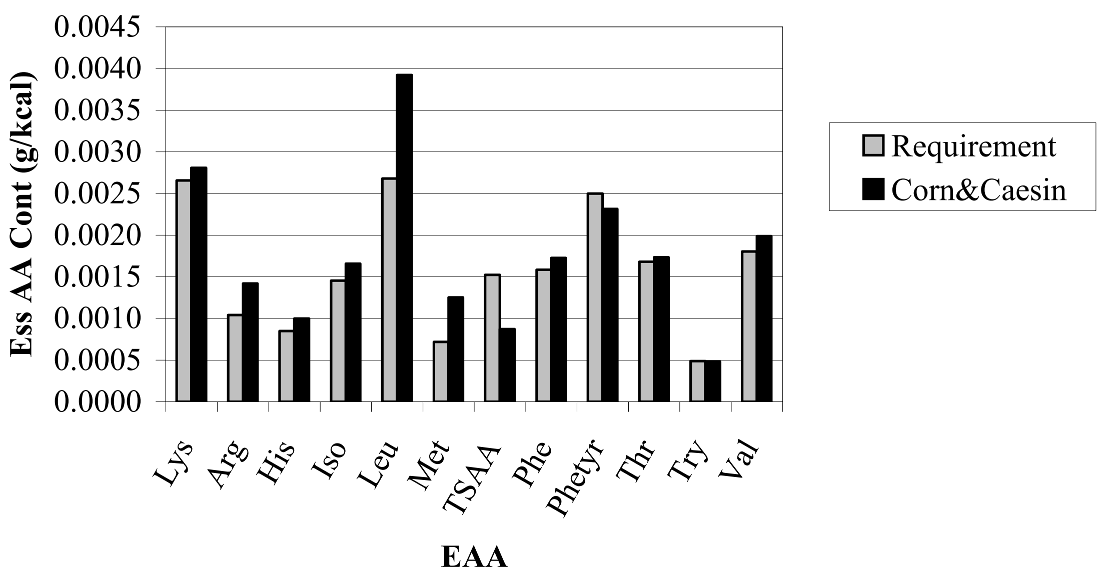

Figure IV-27. The actual essential amino acid profile of the Corn&Casein diet vs. the EAA requirement profile.

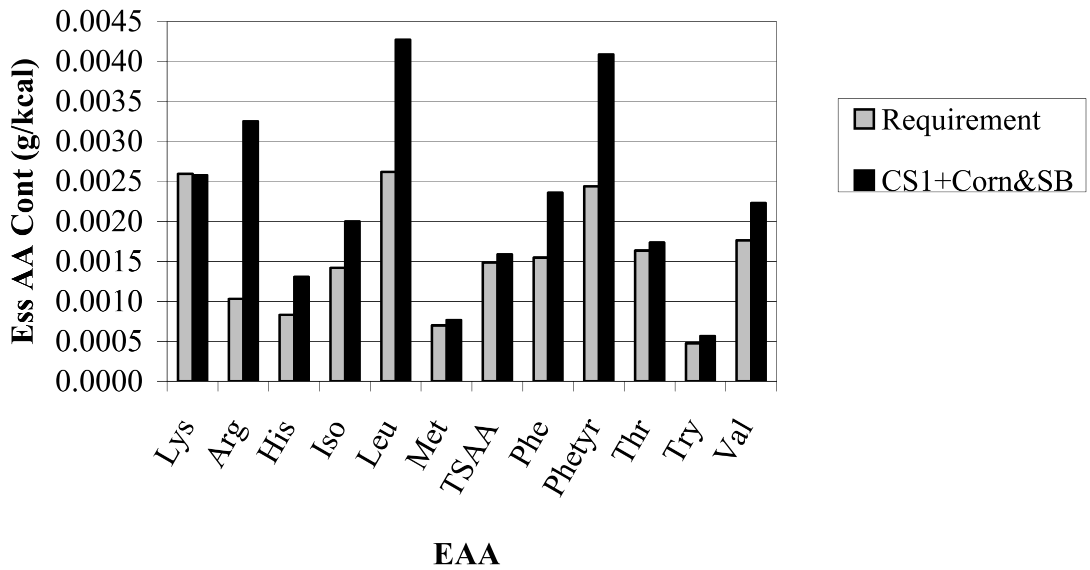

Figure IV-28. The actual essential amino acid profile of the CS1+Corn&SBM diet vs. the EAA requirement profile.

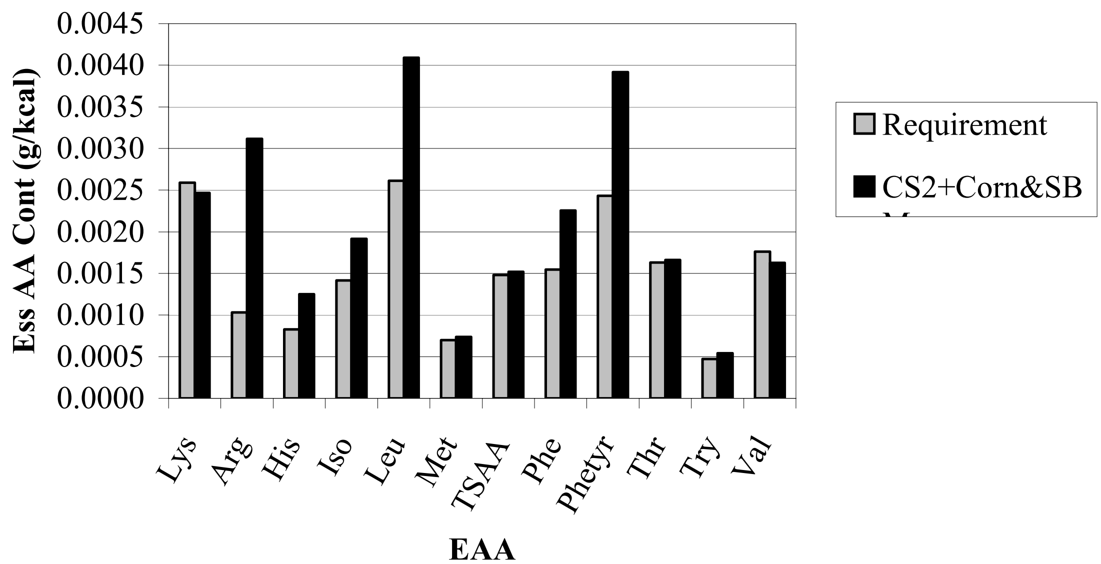

Figure IV-29. **The actual essential amino acid profile of the CS2+Corn&SBM diet vs. the EAA requirement profile.**

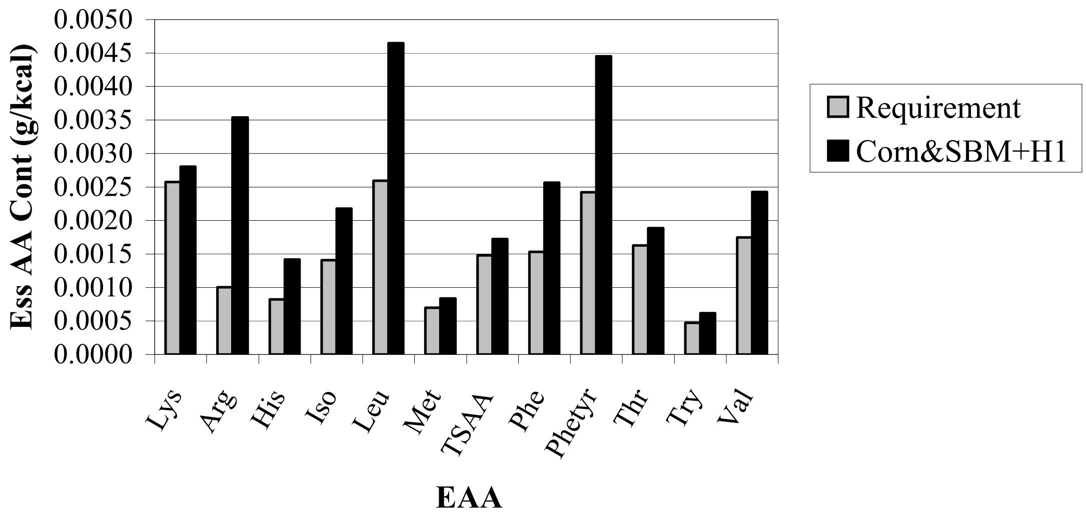

Figure IV-30. The actual essential amino acid profile of the Corn&SBM+H1 diet vs. the EAA requirement profile.

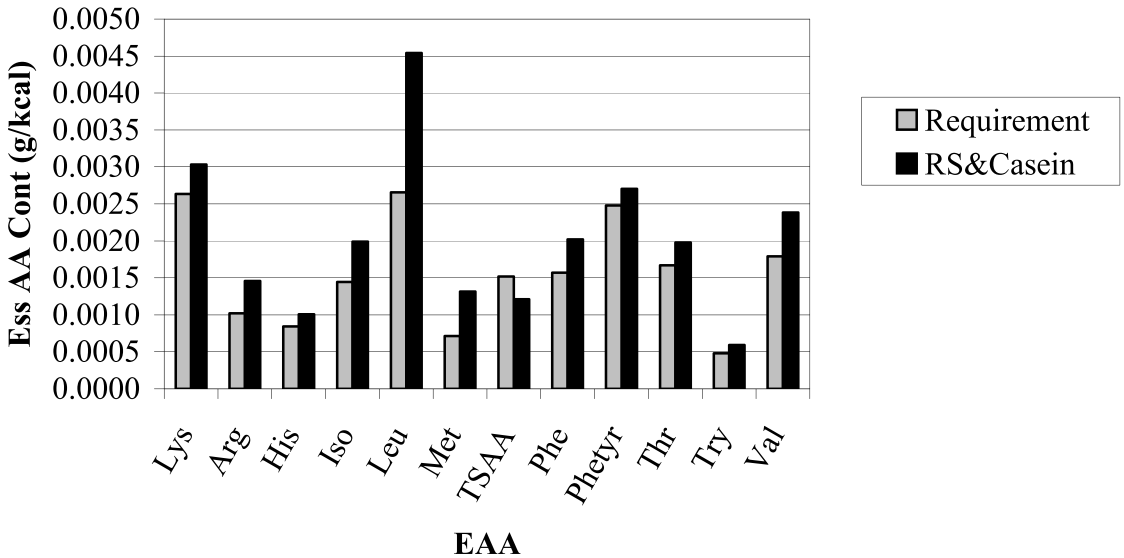

Figure IV-31. The actual essential amino acid profile of the RS-Casein diet vs. the EAA requirement profile.

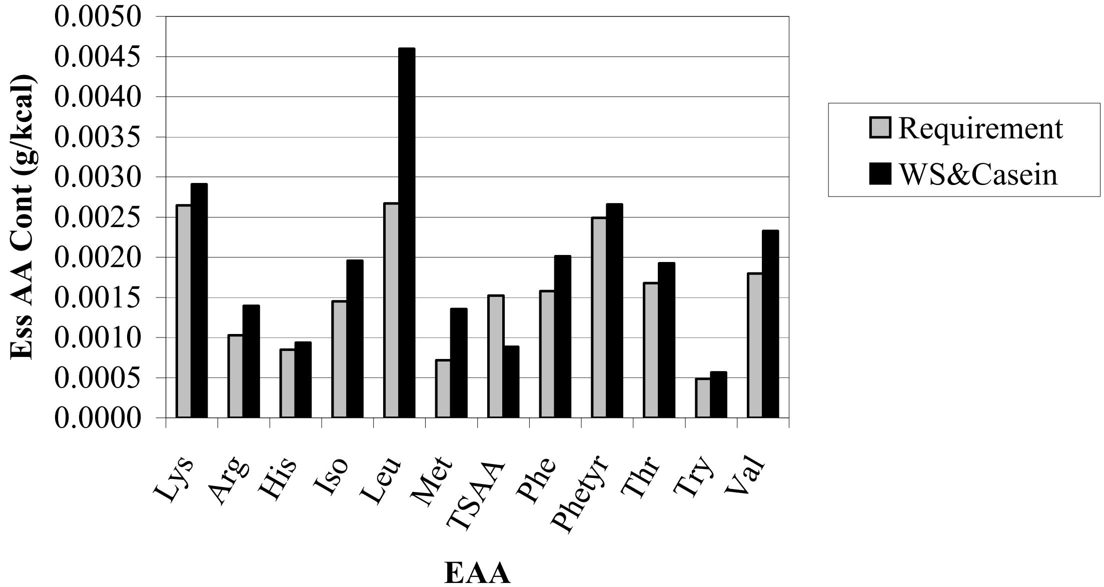

Figure IV-32. The actual essential amino acid profile of the WS-Casein diet vs. the EAA requirement profile.

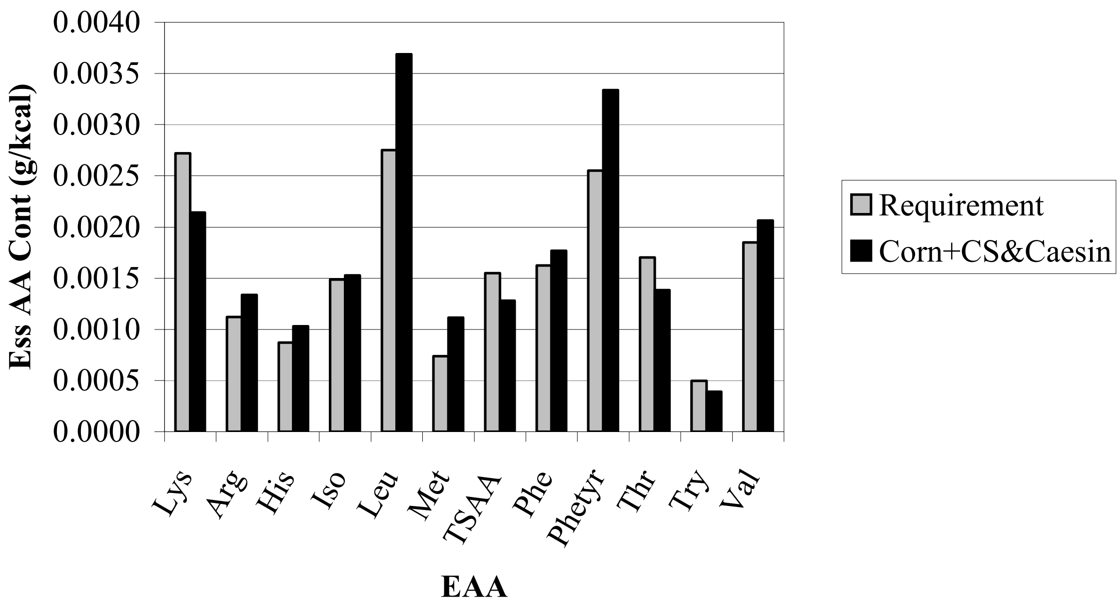

Figure IV-33. The actual essential amino acid profile of the Corn+CS&Casein diet vs. the EAA requirement profile.

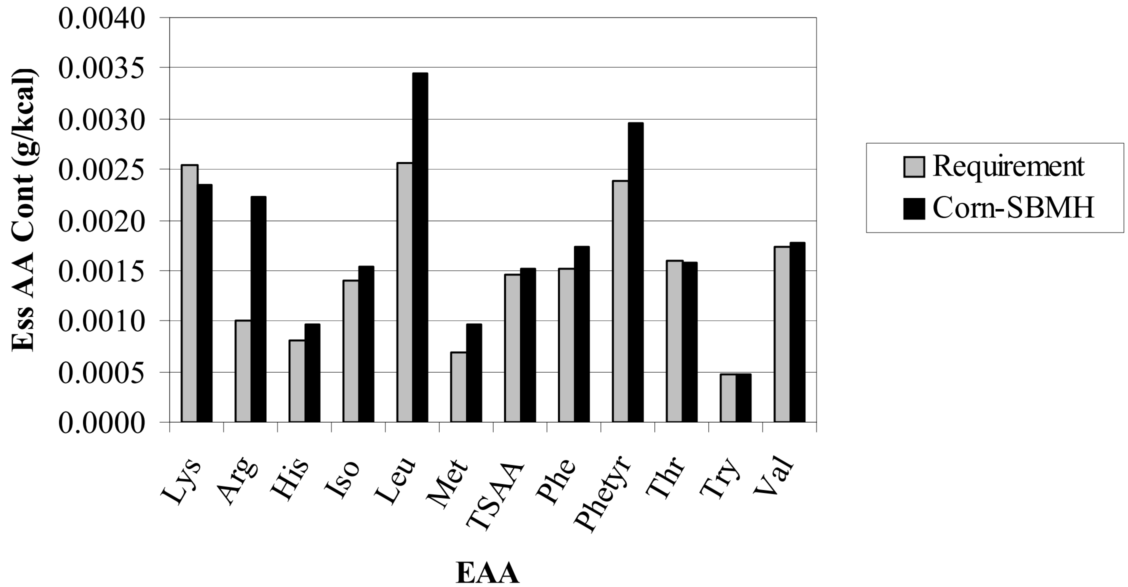

Figure IV-34. The actual essential amino acid profile of the Corn&SBMH diet vs. the EAA requirement profile.

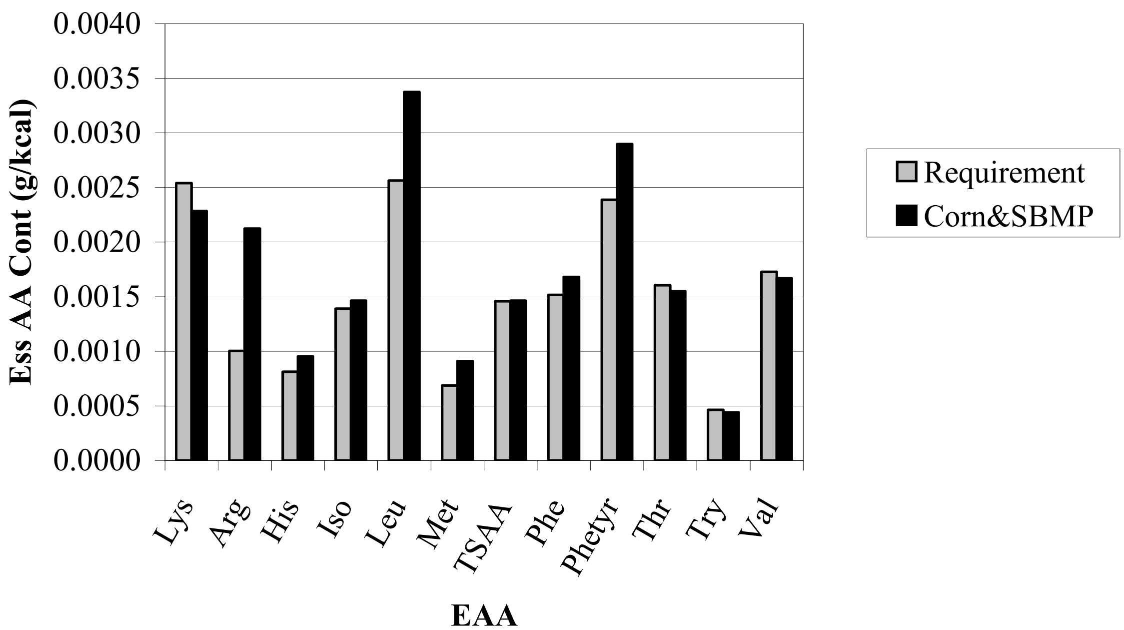

Figure IV-35. The actual essential amino acid profile of the Corn&SBMP diet vs. the EAA requirement profile.

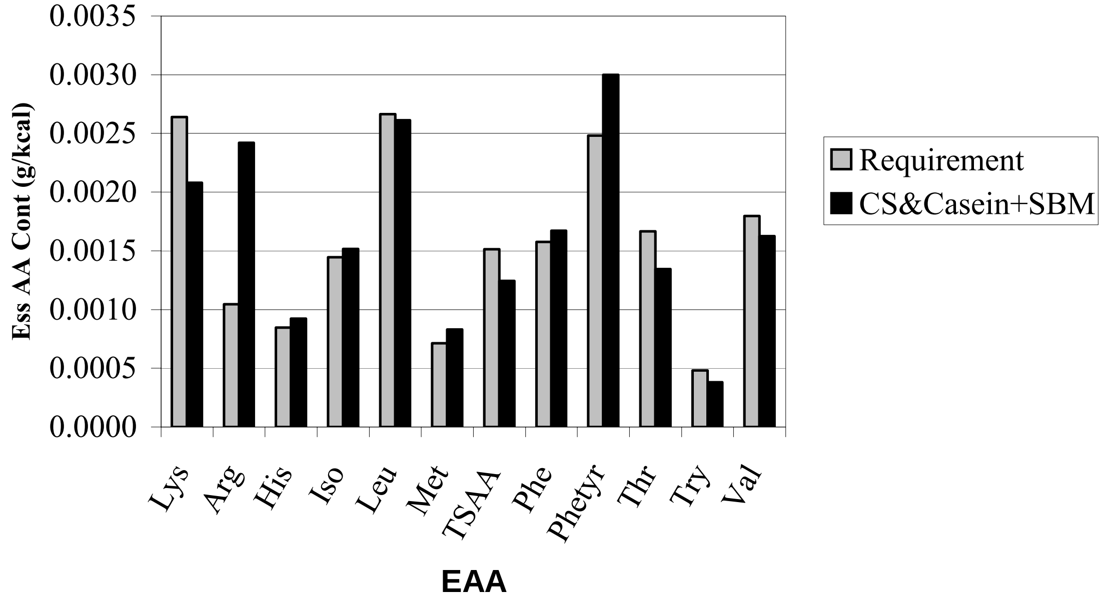

Figure IV-36. The actual essential amino acid profile of the CS&Casein+SBM diet vs. the EAA requirement profile.

Though these low crude protein diets were supplemented with some of synthetic amino acids, Figures 4-12 to Figure IV-30 show that the calculated lysine concentrations (g/kcal) of most of the diets in the group one were all lower than the requirements of pigs fed the Corn-SBM diets. For the diets in this group with protein retentions reduced by 12 percent to 28 percent, the estimated amount of the true ileally digestible lysine were on average 10 percent lower than the requirements. For pigs fed the diet of CS&SBM, CS&SBMH, CS&Casein, and CS&SPC, in which the lysine content was on average 22 percent lower than the equivalent corn-SBM diet, the daily protein retention was 17 to 24 percent lower than those fed the equivalent corn-SBM diet. This result suggests that reduction in protein retention of pigs fed the low-protein, amino acid-supplemented diets in the diet group one may have been caused by the lower intakes of lysine, on a true ileally digestible basis. However, though the daily protein retention was 21 to 28 percent lower for pigs fed the diets of CornA, CornB, CornC, CornD, CornHA, CornHB, CornHC than those fed the equivalent corn-SBM diet, the average lysine content in these diets was 5.8 percent lower than the equivalent corn-SBM diet. The true ileally digestible lysine contents of the corn-SBMH and corn-SPI diets were essentially similar, but daily protein retention was about 11 percent lower for the pigs fed the corn-SPI diet. In addition, the protein retention of pigs fed the corn-SPI diet, of which calculated digestible lysine content was the lowest was not the lowest than that of pigs fed other low-protein, amino acid-supplemented diets. The greater protein retention of pigs fed the corn-SPI diet compared to other ideal protein diet may have been caused by the higher amino acid digestibility coefficients of SPI than those reported in the NRC publication. The protein retention of pigs fed the Corn&Casein and Corn&SBM+H1 was reduced by 12 to 15 percent, though lysine contents in these two diets were 6 to 9 percent higher than the requirement. The lower protein retention of pigs fed low protein, amino acid-supplemented diets thus can not be fully explained by the lower lysine contents in these diets than that required for pigs fed with corn and soybean meal.

Another possibility for the lower protein retention of pigs fed the amino acid-supplemented diets is that other essential amino acids were limiting (Lenis *et al*., 1999). As for lysine, some of these amino acids were added in crystalline form. Figure IV-12 to Figure IV-30 show that the dietary contents of some of the first four limiting essential amino acids, methionine, threonine, or tryptophan were also lower than the requirements of pigs fed the Corn-SBM diets in most of the diets of the group one. The TSAA content in the Corn&Casein diet was 43 percent lower than the requirement. The TSAA content in the diets of CornA, CornB, CornC, CornD, CornHA, CornHB, CornHC was, on average, 26.7 percent lower than the requirement. For the diets of CS&SBM, CS&SBMH, CS&Casein, and CS&SPC, the calculated amount of the true ileally digestible TSAA, threonine, and tryptophan were on average 19.6 percent, 20.5 percent, and 16.9 percent lower than the requirements of pigs fed the equivalent corn-SBM diet. A deficiency of methionine, tryptophan or threonine, compared to the equivalent corn-SBM diet may be the limiting factor that restricts protein retention of pigs fed the low dietary protein, synthetic amino acid-supplemented diets. The calculated concentrations of most of essential amino acids other than the first four limiting amino acids in the industry standard Corn-SBM diet were also much higher than those diets manipulated with ideal protein concept, as shown in the Figure IV-11 to Figure IV-30. Reductions in protein deposition in pigs fed the diets may have also been due to lower essential amino acid intakes other than the first four limiting EAAs.

Pigs in the diet group two had insignificantly smaller or larger protein retention than that expected for the equivalent corn-SBM diet. The protein retention was 3 percent and 6 percent lower for pigs fed the diets of RS&Casein and WS&Casein, respectively, than the standard Corn-SBM diets. The dietary contents of TSAA in the diets of RS&Casein and WS&Casein were 20 percent and 41 percent, respectively, lower than the requirements of pigs fed the equivalent corn-SBM diets. As shown in the Figure IV-31 to Figure IV-32, the calculated concentrations of most of essential amino acids other than the first four limiting amino acids in the diets of RS&Casein, and WS&Casein did not fall below the requirements of equivalent corn-SBM diet. True ileally digestible lysine, TSAA, threonine, and tryptophan intake were 21 percent, 17 percent, 19 percent and 21 percent lower for the Corn+CS&Casein diet than the requirement, though the dietary concentrations of other essential amino acids were similar or even higher. This discrepancy may also have been due to an under-estimate of the digestibility and essential amino acid utilization efficiency for the diet containing casein. The dietary protein in the Corn+CS&Casein diet may be more available for absorption and utilization by pigs.

For pigs fed the diets of Corn&SBMH, Corn&SBMP and CS&Casein+SBM, protein retention was not significantly different than the equivalent corn-SBM diet, though the essential amino acid contents were similar to other low protein, amino acids supplemented diets. Soybean hulls and sugar beets are two of by-products feed, removed from milling a primary product from the initial grain (F-3923, Oklahoma Cooperative Extension Service). According to the report published by Kansas State University (Cooperative Extension Service, Kansas State University, 2000), soybean hulls are the removed during the soybean crushing process in which the soybeans are cracked to a size of 1/6 to 1/8 inch, small enough to facilitate the release of the hull but coarse enough to limit the amount of meat fines. The soybean hull feed that results from milling operations in the production of dehulled soybean meal may contain soybean hulls as well as a portion of the soybean meat that adheres to the hulls. This variability will affect the nutrient content of soybean hull feed. The dietary EAA concentrations of the Corn&SBMH diet were calculated by the nutritional composition of feedstuffs published by the Heartland Lysine, Inc. Since the nutritional value of soybean hulls is largely dependent on the nature and composition of the feedstuff, estimating with those standardized values is expected to result in considerable errors. Similarly, beet pulp is the by-product produced by removing sugar from sugar beets. Its nutrient content may also vary from batch to batch because of milling differences (F-3923, Oklahoma Cooperative Extension Service). The insignificant increase in protein retention for pigs fed the diets of Corn&SBMH, and corn&SBMP, compared to reduction for pigs fed other low protein, amino acid supplemented diets may be attributed to variable nutrient contents of soybean hulls and beet pulp used in the experiments. Similar higher protein retention was observed for pigs fed the diet of CS&Casein+SBM. As described previously, it may be because the actual digestibility and utilization efficiency of essential amino acids in the diets that contain casein were higher than that estimated. The more available dietary protein of casein may be the reason for the higher efficiency of protein retention in pigs fed the CS&Casein+SBM diets, supplemented with crystalline amino acids.

Reductions in whole body protein accretion rates of pigs fed the other low protein, amino acid supplemented diets in the experiments were consistently observed relative to those pigs fed the corn-SBM diet. The crude protein concentrations in most of these low-protein diets were reduced by more than four percentage units, while synthetic lysine, methionine, tryptophan or threonine were supplemented such that the final concentrations were equal to those in the standard corn-SBM diets. The possibility that reduction in protein retention had been caused by the inadequate intakes of non-essential amino acids and essential amino acids other than the first four limiting essential amino acids cannot be excluded. Research reports conflicting results about the effects of reduction in the dietary protein content of the diets on growing pig protein retention. Since non-essential amino acids (NEAAs) may be synthesized in pig bodies from essential amino acid (EAA) intakes, a reduction of two or three percentage units of dietary CP is possible with no reduction in protein retention when essential amino acids are supplemented (Tuitoek *et* *al*., 1997). A low dietary CP content may increase the nitrogen utilization of essential amino acids for NEAA synthesis (Lenis *et al*., 1999). Consequently N utilization efficiency was increased, and N excretion was reduced in such low protein, amino acid supplemented diets. However, some research reported that despite supplementing the first four limiting amino acids, protein retention decreased as the CP contents in diets decreased (Figueroa *et al*., 2002; Carter *et al*., 2003). Otto et al. (2003) reported that protein retention in growing pigs decreased, as dietary CP content decreased from 15 percent to 6 percent. Kerr et al. (1995) found that growing pigs retained less protein, when the CP content in the corn-SBM diet was reduced from 16 percent to 12 percent, supplementing with lysine, tryptophan, and threonine. Pigs fed the corn-SBM diet with 12 percent CP, supplemented with lysine, tryptophan, threonine, and dispensable nitrogen had higher protein retention than those fed the 12 percent CP corn-SBM diet supplemented with lysine, tryptophan, threonine only (Kerr et al., 1995). This may be attributed to insufficiency of certain NEAA that cannot be synthesized at a sufficiently high rate by pigs to meet the animal's total N requirements for protein growth (Lenis *et al*., 1999).

Figure IV-1 and Table IV-16 together were used to evaluate the effect on protein retention of reduction in the dietary crude protein concentration (expressed in percent of feed) of the experimental diets. Dietary treatments shown in the Table IV-16 were classified as the standard corn-SBM diets with crude protein content (percent of feed) 18.56 percent, and low crude protein diets formulated to contain lower percentage of crude protein, supplemented with crystalline lysine, tryptophan, threonine, and methionine. The crude protein concentration (percent of feed) was reduced by 1.5

percent, 3.9 percent, and 3.8 percent in the diets of Corn+CS&Casein, RS&Casein, and WS&Casein, respectively. Similar performance in protein retention compared with the corn-SBM diets were observed for those diets. The analysis on experimental data therefore demonstrated a reduction of less than four percentage units of dietary protein concentration is possible with little or no reduction in daily protein retention when EAAs were supplemented (Tuitoek *et al*., 1997). Table IV-16 shows reduction in protein retention for the low-protein, AA-supplemented diets compared to the standard corn-SBM diets are most evident for the low crude protein diets with crude protein concentration less than 14 percent. For these diets, the lowest protein retention was observed for pigs fed the diets with crude protein concentration reduced by more than 4 percent. Similar poor performance of protein retentions were obtained with the diets of Corn A, Corn B, Corn C, Corn D, Corn HA, Corn HB, Corn HC, CS&SBM, CS&SBMH, and CS&SPC. The daily protein retention of pigs fed the diet of CS&Casein+SBM, in which dietary CP increases for more than 1.7 percent was greater than those fed the standard corn-SBM diet.

In the original NRC model total dietary CP provided by the corn-SBM diet is assumed to be adequate in essential amino acids. The experimental data shows that total protein retention of pigs fed low-protein, amino acid-supplemented diets decreased as the dietary crude protein concentrations decreased as compared with the standard corn-SBM diets. These findings suggest that protein retention is also sensitive to dietary crude protein intake. To determine the effect of dietary CP concentration on protein retention of growing pigs, an adjusted term that represented the essential amino acid content relative to the total dietary crude protein in the diet was included in the protein retention equation.

According to Lenis *et al*. (1999), protein or N retention increased with increasing total dietary N content (TNCont) as NEAAs could be used to realize maximum protein retention as well. Define the N from EAA intake as EAAN, and N from NEAA intake as NEAAN. The effects of ratio of $\mathrm{EAAN/NEAAN}$ on animal protein retention were dependent on the total dietary N content. At the lower total dietary N level, protein retention increased with the increase in $\mathrm{EAAN/NEAAN}$, because essential amino acids is the limiting factor for growth and surpluses of some essential amino acids relative to the requirements could be used as sources of N for the synthesis of non-essential amino acid. In the diets with high total dietary N content, increasing the ratio of $\mathrm{EAAN/NEAAN}$ failed to improve protein retention (Lenis et al., 1999). The extent to which the protein retention performance was reduced when dietary CP was reduced, supplemented with essential amino acids was, therefore, estimated by including TNCont and the interaction $\mathrm{TNCont} \times (\mathrm{EAAN/NEAAN})$ in the initial NRC protein retention equation. That is,

$$\begin{aligned}\mathbf{PRP}_{\mathrm{d}} &= (1-\exp(\beta_1 RAEN_d + \beta_2 TNCont_d + \beta_3 TNCont_d \times RAEN_d)) \times \\ &(17.5e^{-0.0195\mathbf{BW}_{\mathrm{d}}} + 27.52) \times 0.003137\mathbf{MFFL}_{\mathrm{d}} \times 0.94\mathbf{DEA}_{\mathrm{d}} + \boldsymbol{\varepsilon}_{\mathrm{d}} \quad (4\text{-}29)\end{aligned}$$

where $\mathrm{RAEN_d} = \sum_{i=lys}^{val} \mathrm{EAAN_{di}/NEAAN_d}$, the ratio of the N from total digestible EAA intake to the N from the non-essential amino acid intake in a particular diet d.

$\mathrm{EAAN_d} = \sum_{i=lys}^{val} \mathrm{EAAN_{di}}$ is the N from total essential amino acid intake in the diet d.

$\mathrm{NEAAN_d}$ is the N from total non-essential amino acid intake in the diet d.

The result of the regression analysis using experimental data was shown as below.

$$PRP_{dt} = (1 - e^{1.5474*RAEN_d \text{-} 70.6212TNCont_d \text{-} 88.5842RAEN_d \times TNCont_d}) \times (17.5e^{-0.0195BW_{dt}} + 27.52) \times 0.003137MFFL_{dt} \times 0.94DEA_{dt} \tag{4-30}$$

Notice that the previously estimated intercept (Equation 4-24) is retained in the equation. The hypothesis tests show that the effect of the ratio of RAEN, total dietary N content, and their interaction on protein retention was significantly different from zero at the five percent level. The modified protein retention equation that included the ratio of total essential amino acids, total dietary N content, and their interaction was therefore in favor over the initial NRC protein retention equation.

To ensure the protein growth level, essential amino acids must also be adequate. As observed previously, pigs fed the low protein, essential amino acids supplemented diets with less amino acid contents than the equivalent corn-SBM diet generally had lower protein retention. However, pigs fed the diets with essential amino acid profiles that did not deviate much from that of the equivalent corn-SBM diet had smaller reduction in protein retention compared to other low protein diets. Supposing that the essential amino acid intakes were first used to meet the requirement for maintenance, the amount of a particular essential amino acid intake that is available for protein retention was the total amount of that EAA intake minus by the amount required for maintenance. The true ileal digestible lysine required for maintenance ($\mathrm{MEAA_{lys}}$) expressed in grams per day at any body weight as shown in the equation (2-18) (NRC, 1998) is:

$$\text{Lysine for maintenance } (\mathrm{MEAA_{lys}}, \text{g/day}) = 0.036 \times \mathrm{BW_t}^{0.75}.$$

Each of the other amino acids requirements for maintenance can be calculated by multiplying the lysine requirement above by the ideal protein system as follows:

$$\text{Arginine for maintenance } (\mathrm{MEAA_{Arg}}, \text{g/day}) = -0.072 \times \mathrm{BW_t}^{0.75}$$

$$\text{Histidine for maintenance } (MEAA_{His}, \text{g/day}) = 0.012 \times BW_t^{0.75}$$

$$\text{Isoleucine for maintenance } (MEAA_{Ile}, \text{g/day}) = 0.027 \times BW_t^{0.75}$$

$$\text{Leucine for maintenance } (MEAA_{Leu}, \text{g/day}) = 0.025 \times BW_t^{0.75}$$

$$\text{Methionine for maintenance } (MEAA_{Met}, \text{g/day}) = 0.010 \times BW_t^{0.75}$$

$$\text{TSAA for maintenance } (MEAA_{TSAA}, \text{g/day}) = 0.044 \times BW_t^{0.75}$$

$$\text{Phenylalanine for maintenance } (MEAA_{Phe}, \text{g/day}) = 0.018 \times BW_t^{0.75}$$

$$\text{Phe + tyrosine for maintenance } (MEAA_{PheTyr}, \text{g/day}) = 0.044 \times BW_t^{0.75}$$

$$\text{Threonine for maintenance } (MEAA_{Thr}, \text{g/day}) = 0.054 \times BW_t^{0.75}$$

$$\text{Tryptophan for maintenance } (MEAA_{Trp}, \text{g/day}) = 0.009 \times BW_t^{0.75}$$

$$\text{Valine for maintenance } (MEAA_{Val}, \text{g/day}) = 0.024 \times BW_t^{0.75}$$

The amount of lysine and other essential amino acids required for daily protein retention (GEAA) can be expressed mathematically as follows (NRC, 1998):

$$\text{EAA i req. for protein retention } (GEAA_i) = \alpha_i \times PRP_t, \quad i = \text{Lys, His, ..., Val}$$

where $GEAA_i$ is the amount of true ilea digestible EAA i needed for daily body protein synthesis. The value of α_{lys} estimated by the data from experiments (Carter et al., 1999, 2000, 2001, 2003) were shown in the Table 3-24. The α values for essential amino acids other than lysine calculated with the estimated lysine requirement (equation 4-27) and the ideal amino acid pattern recommended by the NRC (1998) were also shown in the Table IV-17.

Table IV-18. The estimated values of ideal amino acid coefficients for protein growth, α_i.

EAA	Lys	Arg	His	Ile	Leu	Met
α_i	0.077	0.037	0.025	0.042	0.079	0.021
EAA	TSAA	Phe	Phetyr	Thr	Trp	Val
α_i	0.042	0.046	0.072	0.046	0.014	0.052

Source: α values for other amino acids than lysine were calculated using the ideal protein ratios given by NRC (1998).

Let $ITEAA_i$ denote the intake of essential amino acid i. The quantity of essential amino acid i that is available for protein retention, $APREAA_i$, is the total intake of essential amino acid i less the amino acid i required for maintenance. That is,

$$APREAA_i = ITEAA_i - MEAA_i, \qquad i = Lys, His, ..., Val. \qquad (4\text{-}31)$$

The amount of essential amino acids available for protein retention, $APREAA_i$, must be greater than or equal to the amount of the ith essential amino acid required for protein retention. The excess essential amino acid intakes beyond that required for growth requirements will be excreted. That is,

$$APREAA_i \geq \alpha_i \times PRP_t \qquad i = Lys, Arg, ..., Val, \qquad (4\text{-}32)$$

where α_i is the protein growth requirement coefficient.

When the intake of each essential amino acid is greater than or equal to that required for protein growth, the EAA requirements of protein retention generated with digestible energy and crude protein intake as estimated in the equation (4-30) are met. In this case, the protein retention estimated with digestible energy and crude protein intake in the equation (4-30) is fully feasible without any limit caused by the shortage of EAAs.

When the essential amino acid profile of the diets was below the essential amino acid requirement profile of the pig's protein growth, protein retention is also dependent on the dietary protein quality that is defined in terms of its relative amino acid profile to amino acid requirement profile of pigs (Fawcett et al., 1978). In the case that the intake of any EAA falls short of that required for protein growth, protein retention is mainly constrained by the most limiting essential amino acid (lysine for all diets in this study). As the true ileally digestible lysine intakes were below the recommended levels, protein retention of the growing-finishing pigs was reduced by the same amount. Reduction in the establishments of other amino acids in pigs can be calculated from the amount of lysine below the animals' requirements with the optimum patterns of essential amino acids. Therefore, the protein retention function into which the insufficient EAAs were incorporated is

$$\mathbf{PR}_{\mathrm{t}} = \mathbf{PRP}_{\mathrm{t}}, \text{if } \mathrm{APREAA}_{\mathrm{i}} \geq \alpha_{\mathrm{i}} \times \mathrm{PRP}_{\mathrm{t}};$$

$$= \mathbf{PRP}_{\mathrm{t}} + (\mathrm{APREAA}_{\mathrm{i}} - \alpha_{\mathrm{i}} \times \mathrm{PRP}_{\mathrm{t}})\boldsymbol{\alpha}'\mathbf{I}_{12}, \text{otherwise.} \quad (4\text{-}33)$$

where $\mathrm{APREAA}_{\mathrm{i}}$ is the amount available for protein retention of most limiting essential amino acids, such as lysine. $\mathbf{I}_{12}$ is an 12×1 identity matrix.

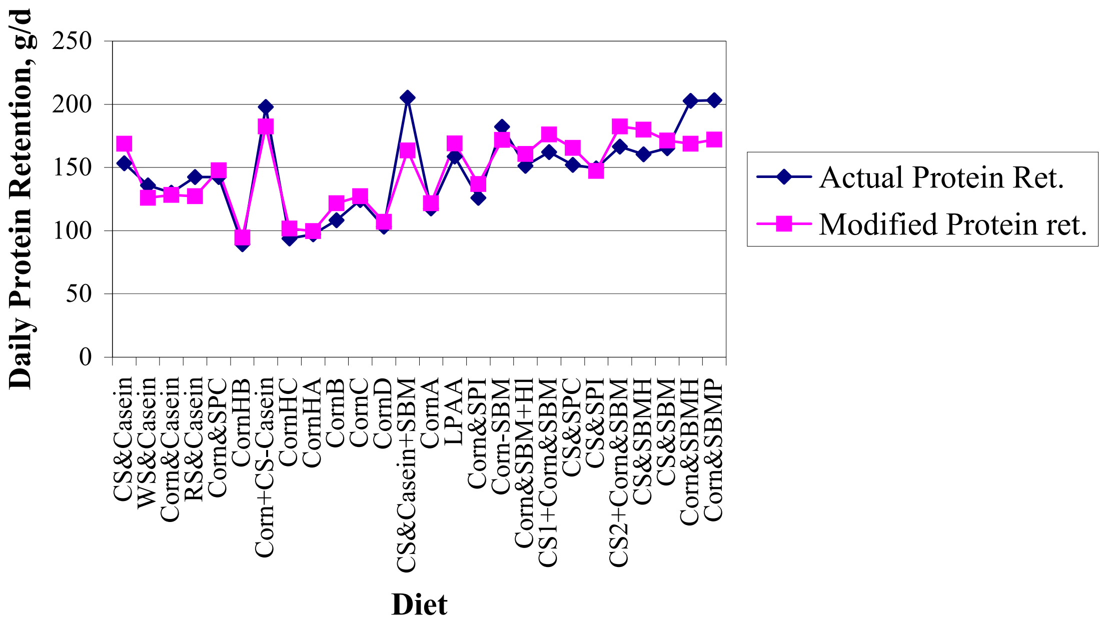

Figure IV-37. Daily Protein Retention (gram/day): the actually values vs. the fitted values with modified protein retention equations, sorted by animal body weight.

Figure IV-37 shows the protein retention of pigs estimated by equation (4-33). The predicted protein retention matched the experimental one very well, except the diets of Corn-SBMH, Corn-SBMP, and CS&Casein+SBM. The protein retention estimated with animal body weight and DE intake also well respond to changes in N content from total essential amino acids, represented by the ratio of $EAAN_d/NEAAN_d$, as long as EAA requirements are met. The protein retention equation also well estimated the effect of EAA intake on pig protein growth. At the EAA intake levels below the requirements, limiting EAA intake reduced the protein deposition rate that could be generated with dietary protein and digestible energy intakes. The under-estimated protein retention for the diets of Corn-SBMH, Corn-SBMP, and CS&Casein+SBM, as described previously, may be attributed to under-estimate of the nutrient content of soybean hull feed and beet pulp, and increases in amino acid digestibility in the diet of CS&Casein+SBM.

The NRC (1998) assumed that phosphorus requirement is mainly determined by digestible energy intake (kcal/day) for a given body weight of pig, as described in the equation (4-9). Digestible P requirements in equation (4-10) estimated by Jongbloed (1987) for growing pigs were also dependent on body weight and expected body weight gain. It has been demonstrated in vast literature in swine growth that body weight gain depends on intake of digestible energy (Fawcett *et al*., 1978; Black *et al*., 1986). Pomar *et al*., 1991) Pig weight gain consists of protein, fat, water, and ash retention. Intake of digestible energy was first used for maintenance and protein retention. Surplus energy is then converted into fat. In fact, the growth rate was primarily restricted by energy restriction in the swine growth manipulation model (Calabotta et al., 1982). Based on the phosphorus requirement equation recommended by the NRC (1998), the regression model was specified as follows:

$$\mathbf{PHR}_{\mathrm{d}} = \mathrm{e}^{-0.0557-0.416(\ln \mathbf{BW}_{\mathrm{d}})+0.005(\ln \mathbf{BW}_{\mathrm{d}})^2} \times \boldsymbol{\beta}_{\mathrm{d}} \mathbf{DEI}_{\mathrm{d}} + \boldsymbol{\varepsilon}_{\mathrm{d}}, \quad (4\text{-}34)$$

where $\mathbf{PHR}_{\mathrm{d}}$ and $\mathbf{DEI}_{\mathrm{d}}$ are the pig phosphorus retention vector, and digestible energy intake vector for diet d, respectively.

The regression equation was in an exponential functional form with DE intake and body weight as the explanatory variables, and phosphorus retention as dependent variable. The limited live weights of pigs in the experimental data render statistic reference for the parameter associated with body weights invalid. Therefore, parameters of body weights in the phosphorus retention equation (4-34) were fixed at the same levels as what the NRC recommended.

For the present, we assume that the parameter vector β_d is the same for all diets. The daily bio-available phosphorus requirements (PHR_t, g/day) were estimated by stacked data on P retention (Carter *et al*., 1999; 2000; 2001) as follow:

$$\begin{aligned} &\text{Daily Digestible P Requirements } (PHR_t\text{, g/day}) \\ &= e^{-0.0557-0.416(\ln BW)+0.005(\ln BW)^2} \times \underset{(0.000104)}{0.3255} \times DEI_t \end{aligned} \quad (4\text{-}35)$$

The estimated standard errors are shown in the parentheses. The parameter value recommended by NRC (1998) is the reciprocal of DE content in kcal per gram feed. The null hypothesis of $H_0 : \beta = 0.294$ was tested to determine whether the NRC prediction for farm is different from that estimated with all experimental diets. From the SAS output, the p-values of Wald, L.R., and L.M. test are all smaller than 0.0001. Therefore, the NRC parameter value was rejected in favor of the re-estimated with all experimental data on P retention at one percent significance level. Since all the experimental data comes from animals housed individually in metabolism chambers, while the NRC simulation model is based on the farm where pigs are fed under commercial conditions, the smaller estimated value of β than the NRC predictions may reflect the lower P utilization efficiency by pigs in the metabolism chambers of laboratory than those raised on farms.

The digestible phosphorus requirement of the NRC model was estimated based on the corn-SBM diet, in which total phosphorus content is abundant. The analysis on actual phosphorus retention in Figure IV-8 shows that as the total dietary P concentration decreased, P retention of pigs decreased as compared with the standard corn-SBM diets. These findings suggest that total dietary phosphorus intake may also affects pig phosphorus retention. To account for the effect of total dietary P concentration on phosphorus retention of growing pigs, an adjustment factor that reflected the bio-available P content relative to the total dietary P content in the ith diet was included in the phosphorus retention equation. The extent to which the P retention was affected when total dietary P was reduced by replacing ingredients with high bio-available P or phytase in the diets was estimated with the following regression model:

$$\begin{aligned}&\text{Daily Available P Requirements } (PHR_{dt}, \text{g/day}) \\ &= e^{\beta_0+\beta_1 RAPI_d+\beta_2 RAPI_d^2} \times e^{-0.0557-0.416(\ln BW_t)+0.005(\ln BW_t)^2} \times 0.3255 DEI_{dt} + \varepsilon_{dt}\end{aligned} \tag{4-36}$$

where $RAPI_d = API_d / TPI_d$, the ratio of the bio-available P intake to the total P intake in a particular diet i. API_d is the total available P content in the diet i. TPI_i is the total P content of the diet i. Notice that the previously estimated intercept (Equation 4-35) is retained in the equation.

The result of the regression analysis using experimental data was shown as below.

$$\begin{aligned}&\text{Daily Available P Requirements } (PHR_{dt}, \text{g/day}) \\ &= e^{4.7-21.8RAPI_d+34.4RAPI_d^2-18.2RAPI_d^3} \times e^{-0.0557-0.416(\ln BW_t)+0.005(\ln BW_t)^2} \times 0.326 DEI_{dt} \\ &\quad (2.1)\ (9.5)\quad (13.9)\quad (6.6)\end{aligned} \tag{4-37}$$

The estimated standard errors are shown in the parentheses. The null hypothesis that the ratio of bio-available P content to total P content in the diet has no effect on P retention was rejected at five percent significance level.

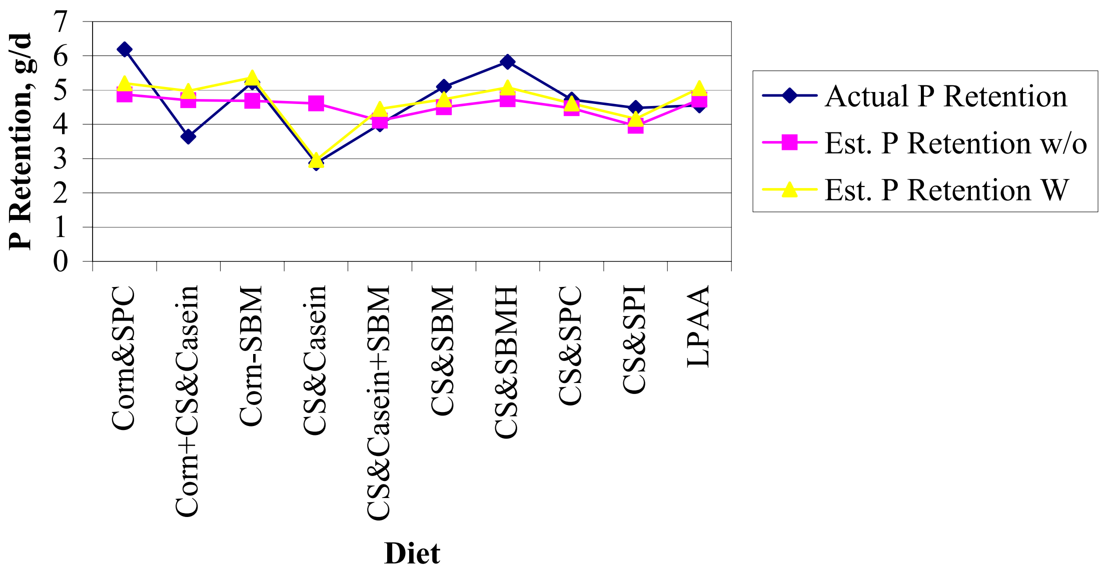

Figure IV-38. Daily Phosphorus Retention (gram/day): the actual values vs. the estimated values of the modified phosphorus retention equations with and without the adjustment term of bio-available P.

Figure IV-38 shows the P retention of pigs estimated by equation (4-37) as well as the P retention of pigs estimated by equation (4-35). In general, the modified phosphorus retention equations with the adjustment term of bio-available P performed better than that without the adjustment term. The re-estimated P retention with experimental data may not well adjust to changes in P retention, as total and available P concentrations (represented by the ratio of API_d/TPI_d) change. The predicted P retention incorporating bio-available P content in the diets into consideration matched the actual ones very well, except for the diets of Corn-SPC, and Corn+CS&Casein. This demonstrated that in addition to body weight and DE intake, the bio-available P content in the diet is also an important factor of determining animal P retention. The study used calculated bio-available P contents in the regression and simulation analysis. The under or over estimated P retention for the diets of Corn-SPC, and Corn+CS&Casein may be attributed to erroneous calculated bio-available P contents in those diets.

The data of Experiment 10 were used to measure improvement in dietary digestibility of phosphorus (P) with microbial phytase supplementation. The net P absorption was calculated by subtracting the excretion amount of P in feces from P intake. The digestibility of phosphorus is defined as the ratio of P absorption to P intake. Three dietary treatments supplemented with increasing amounts of the solid-state fermented phytase, the basal diet plus 250, 500, and 1,000 phytase units per kg feed intake, were used to quantify the effect of the phytase on P digestibility of the corn-SBM diet. The procedure uses linear regression of the net P absorption on P intake.

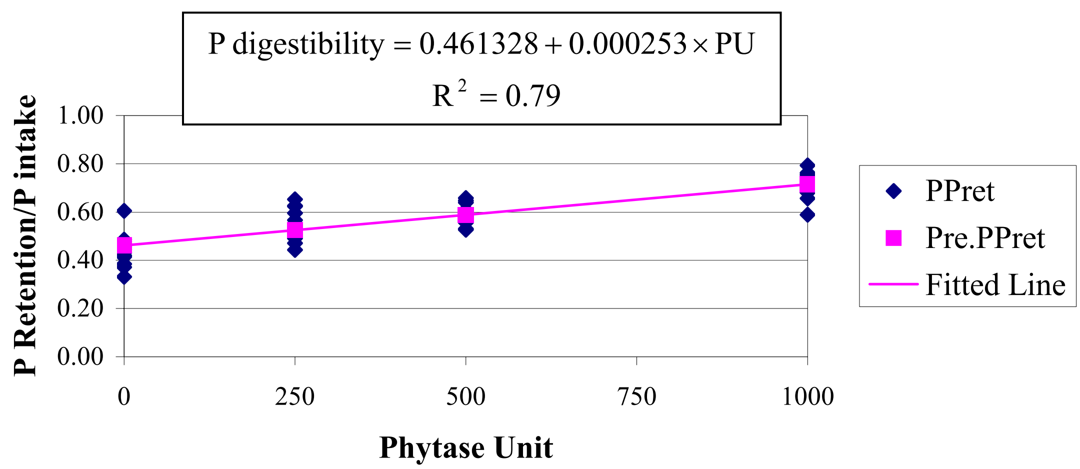

Figure IV-39. Fitted and observed relationship for the effect of phytase addition.

Figure IV-39 demonstrated the effects of phytase addition to corn-SBM diets on phosphorus digestibility in growing pigs.

$$\text{P digestibility} = 0.461328 + 0.000253 \times \text{PU}, \quad R^2 = 0.79 \tag{4-38}$$

The estimated slope is defined as the digestibility coefficient of the phytase source. The fitted line shows that the P digestibility improved as the phytase content in the diets increases. The P digestibility in the low-phosphorus diets supplemented with 250, 500, 750 and 1000 PU of phytase was improved for 6.3, 12.7, 19.0 and 25.3 percent, respectively.

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CHAPTER V

THE INTEGRATED FEEDING MANAGEMENT

The confined and intensive feeding of modern swine production requires better housing system and improved operations. Besides advantages from economics of size, concentrated and intensive swine feeding operations have also drawn serious environmental criticisms. Growing pigs contribute up to 71 percent of the total nitrogen excretion, and 75 percent of the total phosphorus excretion from swine production (Dourmad, 1999). The modified NRC swine growth and nutrient requirement model described in Chapter VI provides a basis to estimate nitrogen and phosphorus excretion from alternative diets. Swine rations formulated with the growth and nutrient requirement model in which the N and P content of feed ingredients and requirements were expressed in the true ileal basis sould result in the minimum nitrogen and phosphorus excretion, even if the environmental factors were not considered. Excreted nutrients can be traced to undigested, and unbalanced fractions of the diet, to nutrients given in excess to the animal's requirements, and to the inevitable catabolism (Portejoie *et al*., 2004). Better knowledge of the requirements can allow the manager to decrease the amounts of excreted nutrients in animal manure. Supplying feed with a nutrient profile more agreeable with the requirements can further reduce nitrogen excretion. The swine growth and nutrient requirement model in Chapter IV, and N and P contents in the feedstuffs published by the NRC (1998) and Heartland Lysine, Inc. (Chicago, IL) are guides to formulate diets with better nutrient balance. The nutrient requirements in the modified growth and nutrient requirement model were presented on the true ileal digestible or bio-available basis, as this facilitates achieving the goal of feeding to requirements. However, although the diet formulated by the profit-maximizing model of Chapter III did consider nutrient quality and quantity, the waste management components are not directly accounted for in the profit maximizing swine diet formulation. Traditional swine diets that were rich in nutrients to insure maximal animal growth may have negative environmental effects. As stricter legislations is passed by the federal and state governments to regulate animal manure disposal, the introduction of environmental objectives in the ration formulation process becomes necessary. The manager must not only consider the ingredient cost but also the cost to manage excess nutrients.

A Prediction Model of N, P, and DM Excretion

This chapter will present the method that will be used to calculate the amount of nutrient excretion with the growth and nutrient requirement model. In addition to the feed cost, the waste management cost associated with the nutrient content of manure through diet manipulation will be estimated by the decision support waste management program (Stoecker *et al*., 2002). Both the effects of diet modifications on animal growth and nutrient excretion will be discussed in the overall optimization model. The simulation model assumes the nutrient content of the feeds in the diet is given by published feed tables. Considerable attention is devoted to determining whether differences between the expected (book values) and the actual (chemical assay) values for crude protein, phosphorus, and dry matter accounted for the differences between expected and observed or actual outcomes.

To incorporate waste management components into the profit maximization problem of swine feeding operations, a model estimating the total amount of nitrogen, phosphorus, and dry matter excreted by the pig at different physiological stages and production levels is developed in the present work. The prediction model will be used to estimate the daily amount of nitrogen, phosphorus, and dry matter excretion (grams per day) from calculated nutrient intake and retention. In the next section, the results of predictions concerning N, P, and DM excretion by growing pigs will be presented. The method used to quantify nutrient excretion is determined by the difference between dietary nutrient intake and the amounts of each nutrient retained by the animal. The intake of N, P, and DM can be estimated from the quantity of feed consumed and the concentrations of the nutrients in the diet. The expected intake calculated from feed tables is compared with feed assay values.

Predicted Nitrogen Excretion

The amount of nitrogen excreted on a daily basis was determined as the difference between nitrogen intake and total nitrogen retention in the pig body. Nitrogen intake was calculated by multiplying the nitrogen content of each feed in a diet by the feed intake. Daily body protein retention or whole body protein gain was estimated by the modified swine growth and nutrient requirement model presented in the chapter IV (equation 4-33).

$$WBPG_t = \mathbf{PRP}_t, \text{if APREAA}_i \geq \alpha_i \times \text{PRP}_t;$$

$$= \mathbf{PRP}_t + (\text{APREAA}_i - \alpha_i \times \text{PRP}_t)\boldsymbol{\alpha}'\mathbf{I}_{12}, \text{otherwise.}$$

N output was then obtained by the difference between N intake and N retention.

Estimated daily body protein retention during the growing-finishing period depends on body weight and growth rate. Nitrogen excretion is also affected by body weight and growth rate. It must be pointed out that the protein retention equation (4-33) can be adaptable to a range of genotypes.

Nitrogen retention (NR) is calculated from the simulated protein retention. The protein deposition in pig body can be partitioned into essential and non-essential amino acid retention. The amount of protein deposition from essential amino acid can be calculating as the total truly ileal digestible amount of balanced essential amino acids provided by the diet or the total amount of essential amino acids retained by the animal. The difference between the total amount of each essential amino acid retained by the animal and the total protein retention is the non-essential amino acid fraction of the body protein retention. The essential amino acid fraction of total body nitrogen deposition is the sum of the retained nitrogen fraction of each essential amino acid (Brody, 1999). Table V-1 gives the nitrogen content of each essential amino acid. It is generally accepted that one gram of nitrogen corresponds to 6.25 g of protein (Bailleul *et al*., 2001). The non-essential amino acid fraction of daily body nitrogen deposition was cal;culated as the difference between the total protein retention and the amount of total essential amino acid retained by animals divided by 6.25. That is,

$$\text{NR}_t = \sum_{\text{Lys}}^{\text{Val}} \text{N}_i \times \text{EAA}_i + (1/6.25) \times (\text{PR}_t - \sum_{\text{Lys}}^{\text{Val}} \text{EAA}_i), \tag{5-1}$$

where N_i is the nitrogen content of essential amino acid i. EAA_i is the amount of essential amino acid i.

Table V-1. The nitrogen portion of each essential amino acid.

	Lys	Arg	His	Ile	Leu	Met	TSAA	Phe	P+T[a]	Thr	Try	Val
N_i	0.19	0.32	0.27	0.11	0.11	0.09	0.10	0.09	0.08	0.12	0.14	0.12

Source: Tom Brody, 1999.
[a] P+T=Phenylalanine+Tyrosine.

The total daily nitrogen intake (TNIT) must meet the nitrogen requirements for retention, maintenance, and inevitable metabolic losses. In the simulation model for nitrogen excretion, daily nitrogen intake was estimated by multiplying the calculated N content of each diet by the daily amount of feed intake. The estimated total nitrogen intake is given in crude units, which also include the indigestible, unbalanced and excess fractions.

Figure V-1 and Appendix Table A5-1 show that total nitrogen intake estimated by the calculated content of total N in the diet and feed intake was in keeping with the actual total nitrogen intake with the exception of CS&Casein+SBM, Corn&SPC, Corn&SPI, and Corn&SBM+H1 diet. The calculated total N intake was higher than actual N intake where the actual protein content was lower than published values. In most diets, there was no real difference between calculated and actual total N intake.

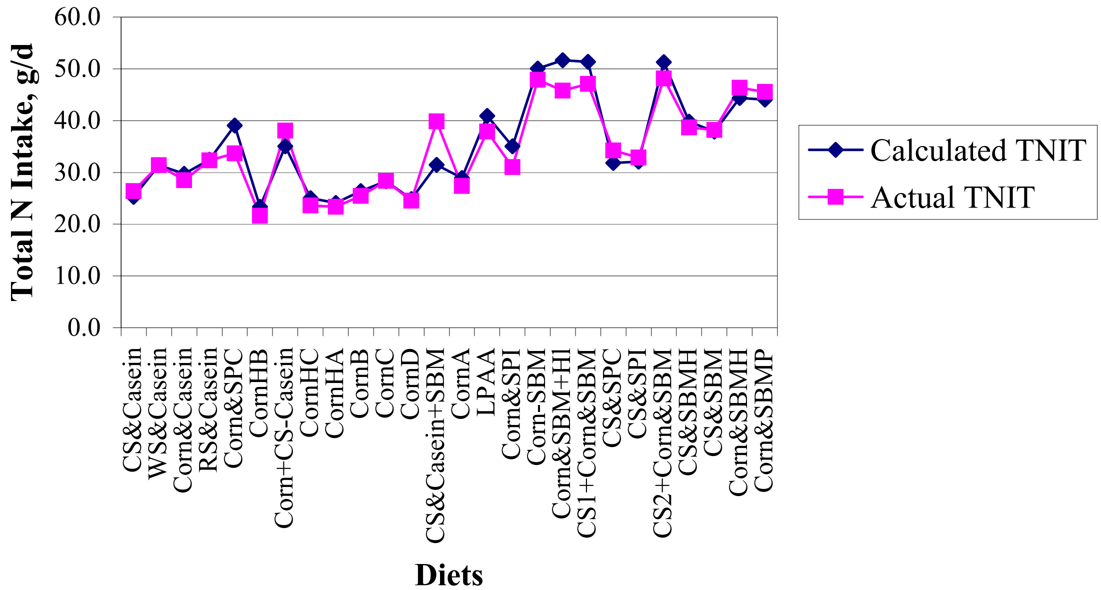

Figure V-1. The calculated and actual total nitrogen intake (TNIT, g/d) for different diets, sorted by animal body weight.

In the CS&Casein+SBM diet, the calculated total N intake was about 21 percent lower than the actual total N intake. The calculated concentration of dietary N was 6 percent lower than the analyzed N concentration. In the Corn&SPC, Corn&SPI, and Corn&SBM+H1 diet the calculated N concentration of diets was 2 percent higher than the analyzed value, while the calculated total N intake was about 13 percent higher than the actual total N intake. Total N intake was higher in the standard corn-SBM diets than was the N intake in the low crude protein diets formulated with highly digestible feedstuffs and synthetic AA supplements.

The simulated N excretion (NExc) by pigs was obtained by subtracting the stimulated N retention from the calculated total intake of N. The simulated N excretion includes the indigestible, unbalanced and excess N from the diet, maintenance, and inevitable endogenous loss due to animal metabolic inefficiencies (Bailleul et al., 2001).

The amount of N excreted due to metabolic loss is obligatory due to maintaining animal performance, and cannot be reduced by changing diet composition. However, the hypothesis is that both the total N content of the diet and total N intake can be lowered through dietary manipulation and that this will reduce N excretion.

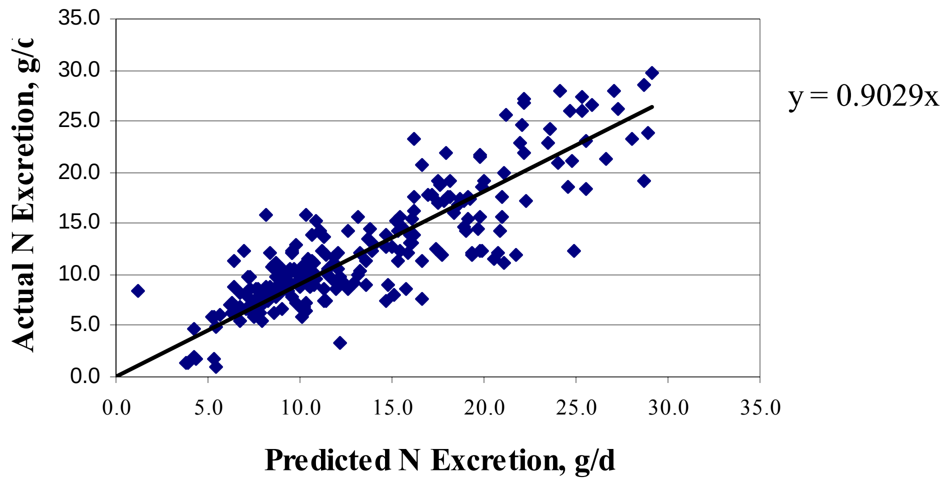

Figure V-2. The relationship between simulated and actual N excretion (NExc), g/d.

The simulated and actual values for nitrogen excretion are compared in Figure V-2. The following linear regression model was used to test whether the values of N excretion in the simulation model were significantly different from actual N excretion. The model is:

$$NExc_t = \alpha NExcS_t, \tag{5-2}$$

where $NExc_t$ and $NExcS_t$ are the actual and simulated total N excretion, respectively.

The parameter α was tested against one to determine the predictability of the model for total N excretion. The estimated relationship between actual and simulated total N excretion was shown in the equation (5-3).

$$NExc_t = 0.903 NExcS_t. \quad (5\text{-}3)$$
$$(64.79)$$

Figure V-2 shows the simulated N excretion was in good agreement with the actual values, and the variation between the actual and simulated N excretion was not significant at the one percent level. The null hypothesis that α was equal one was not rejected by the experimental data so it can be concluded that the simulated values of total N excretion agree well with the experimental values reported by Carter et al. (1999; 2000; 2001; 2003).

Predicted Phosphorus Excretion

Determination of phosphorus excretion is similar to that for the nitrogen excretion. Phosphorus excretion during growing to finishing period ($PExc_t$) was estimated as the difference between total daily phosphorus intake ($TPIT_t$) and daily body phosphorus retention (PHR_t). The daily P retention was estimated according to body weight and digestible energy intake for growing pigs with Equation (4-37) as follows:

$$\text{Daily P Retention } (PHR_{dt}, \text{g/day}) = e^{4.7-21.8RAPI_d+34.4RAPI_d^2-18.2RAPI_d^3} \times e^{-0.0557-0.416(\ln BW_t)+0.005(\ln BW_t)^2} \times 0.326 DEI_{dt}$$

It must pointed out that the growth rate and the pig's initial body weight which determine daily P retention also influence the amount of P excreted by pig.

The total dietary P content of the ration and thereby total P intake affect the amount of P excreted in manure. Total daily P intake in the simulation model was calculated by multiplying the calculated P content of the diets by the simulated amount of daily feed intake. The simulated total P intake is in crude units, which includes the bio-available and the indigestible fractions, as well as any excess P supply. Only the bioavailable P can be used for growth (NRC, 1998).

The simulated and actual total P intake for different diets are compared in Figure V-3 and in Appendix Table A-29. The values for actual P intake and stimulated P intake are close with the exception of Corn+CS&Casein and LPAA diet. However, the regression analysis and Figure V-4 show that the null hypothesis of no difference between simulated and actual P intake could not be rejected at one percent level. The simulated P intake was higher than the actual P intake in the Corn+CS&Casein and LPAA diets, which reflected the fact that the analyzed values were lower than the published values for total P. As expected, the higher P intake was observed in the standard Corn-SBM diet than in the diets formulated with feedstuffs of highly P availability.

The total amount of phosphorus excretion in manure on a daily basis was estimated as the difference between total P intake and retention. That is,

$$PExc_t = TPIT_t\text{-}PHR_t. \tag{5-4}$$

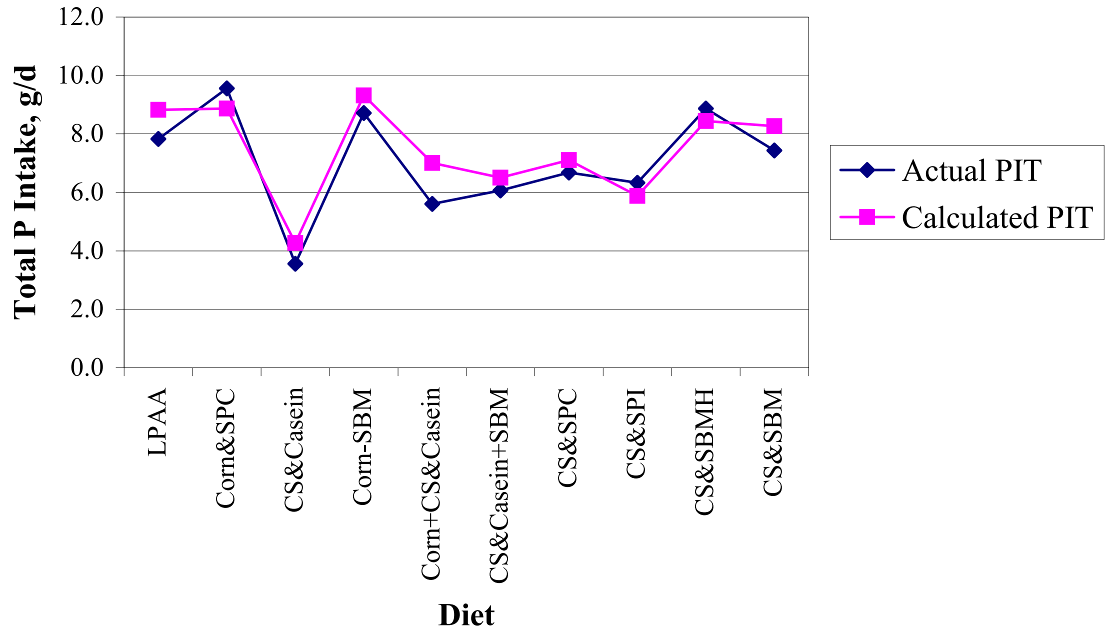

Figure V-3. The calculated and actual total P intake (PIT, g/d) for different diets, sorted by body weight.

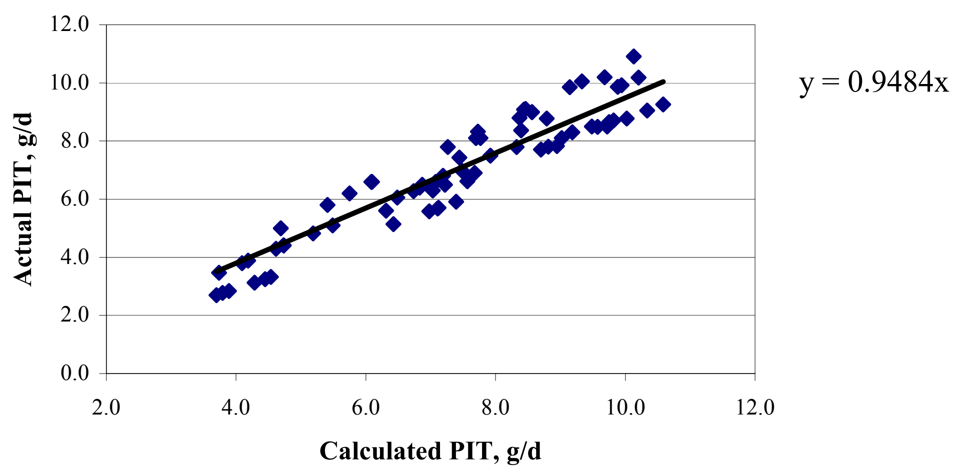

Figure V-4. The relationship between simulated and actual total P intake (PIT), g/d.

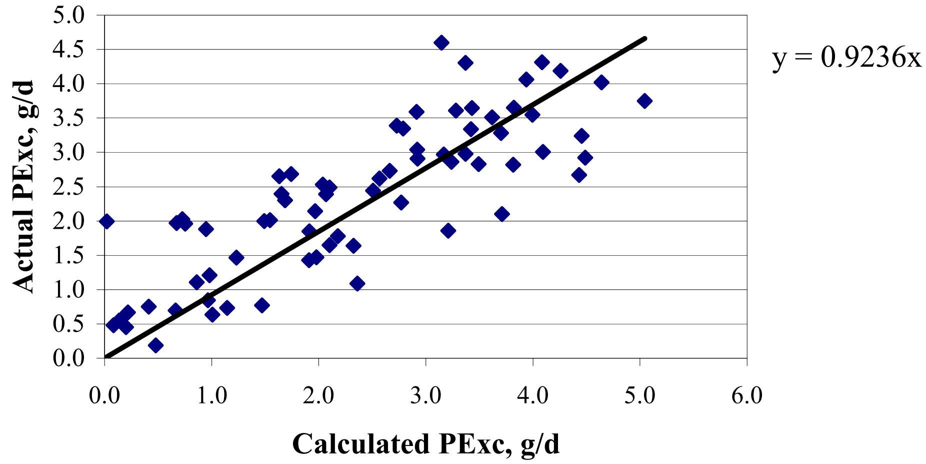

Figure V-5. The relationship between simulated and actual total P Excretion (PExc), g/d.

Figure V-5 shows the relationship between simulated and actual amount of total P excretion. The linear regression of the actual P excretion on simulated P excretion is shown in the equation (5-6).

$$PExc_t = 0.9236 PExcS_t, \qquad (5\text{-}5)$$
$$(28.68)$$

where $PExc_t$ and $PExcS_t$ are the actual and simulated total P excretion, respectively. Figure V-5 and the result of hypothesis test from equation (5-5) shows the simulated values were not significantly different than the actual values of total P excretion at the one percent level.

Total P intake and excretion is influenced by the enzyme phytase and the amount of inorganic P added to the diets. Phytase and/or inorganic P are often used to increase the bioavailable P that is insufficient in the ration formulated with feedstuffs of plant origin. Microbial phytase supplementation can improve phytic acid P bioavailability of plant origin feed, as shown in studies on P digestibility (Park, 2003). Because the efficiency of P utilization is improved by the presence of phytase, total P intake and excretion are reduced in the diet supplemented with phytase instead of inorganic phosphorus. The analysis of the effect of microbial phytase on P bio-availability from feed of plant origin in Chapter VI found that the P digestibility was enhanced by 6.3, 12.7, and 25.3 percent, respectively, for the low available P corn-SBM diets supplemented with 250, 500, and 1000 PU of phytase (Carter et al., 2003). The bioavailability of phytic acid P may be also improved by using phytase-rich cereal feeds such as triticale and wheat by-products. These feeds have 1500 to 2000 PU/kg phytase activity, while the phytase activity is 400 and 600 PU/kg in wheat and barley. In the overall profit maximization model, the total P intake of pigs that was enhanced with cereal phytase or microbial phytase supplement in the diets will be simulated with the estimated relationships between phytase level and the corresponding phytic P availability in feed ration. Microbial phytase and phytase-rich cereals will be assumed to increase P digestibility from 12 to 22 percentage units, depending on the quantity of phytase units added. Total P intake and excretion are expected to be lower for the diets added with phytase than those supplemented with inorganic P.

Predicted Dry Matter Excretion

The amount of manure is mainly determined by its dry matter (DM) content. The amount of dry matter excretion (DMExc) in the manure was estimated from the calculated amount of dry matter intake (DMIT) by subtracting the retained portion of dry matter intake (DMRet). That is,

$$DMExc = DMIT - DMRET. \tag{5-6}$$

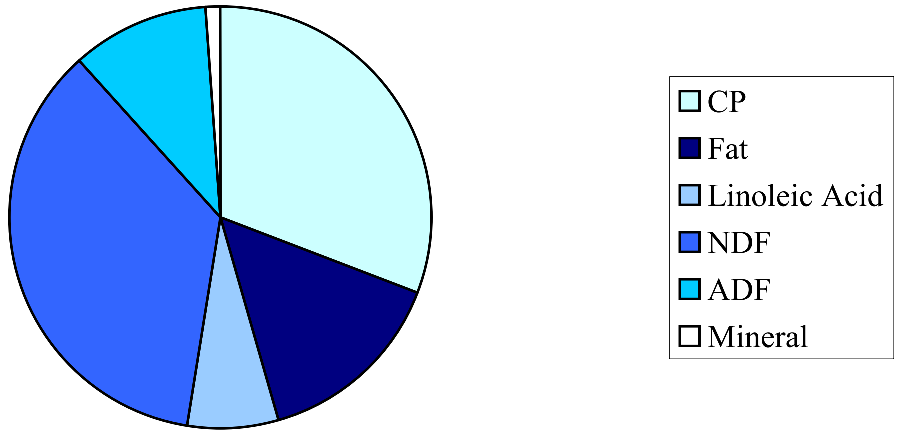

Figure V-6. The Chemical Composition of Grain Corn.

The composition of feed ingredients can be divided into crude protein, fat, non-structural carbohydrates (sugars, pectin and starches), and structural carbohydrates (i.e., neutral detergent fiber), and ash (i.e., mineral) component, as illustrated by chemical composition of grain corn in Figure V-6. The daily amount of dry matter excreted by the animal could be predicted as the difference between the total DM intake and the retained portion of DM intake from dietary protein, carbohydrate, and mineral sources in the diet. Since the digestibility coefficients of dry matter were not available in feedstuff nutrient reports, we developed a prediction equation for the DM retention as follow:

$$DM\,\mathrm{Re}t,\ g/d = WBPG + DM\,\mathrm{Re}tEG + AS\,\mathrm{Re}t, \qquad (5\text{-}7)$$

where WBPG is the daily protein gain of pigs, which is represented the daily protein retention by pigs. DMRetEG is the DM retention from digestible carbohydrate sources in the diet. ASRet is the retained mineral intake. ASRet was estimated from the amount of ash in pig daily body weight gain. All variables are in grams per day. The daily amount of dry matter retention by the animal is the amount of retained DM intake from crude protein, carbohydrates, and mineral sources in the diet. The assumptions and literature sources used to derive the components of Equation (5-7) are described below.

The daily amount of protein retained by pigs was estimated from the total dietary crude protein and amino acids retention as described in the Chapter VI. The energy sources of the feed ingredients generally consisted of non-structural carbohydrates (NSC) and fat as well as structural carbohydrates defined as fiber insoluble in a solution of boiling detergent at a neutral pH, or neutral detergent fiber (NDF). The non-structural carbohydrates portion of the feed ingredient contains almost fully digestible sugar and starches. The NDF is basically the plant cell wall without its inner contents. NDF is made up of four main chemical components: cellulose, hemicellulose, lignin and chitin (Robinson, 1999). Cellulose and hemicellulose can be partially broken down into simple sugars and ultimately ferments into volatile fatty acids that are absorbed. But they are only partially digestible. Due to their complex chemical structures, they resist the attack of digesting microorganisms in pig digestible tract. The other main components of NDF, lignin and cutin are virtually indigestible in both the rumen and lower intestines. Furthermore, both lignin and cutin inhibit digestion of cellulose or hemicellulose either by physical or chemical shielding (Robinson, 1999). As fat and NSC are fully available energy sources with fixed energy content in the diet, the DE intake requirement may be a reasonable proxy variable for the DM retention from NSC and fat intake. The NDF content in feed is also important in estimating the DM retention of feed ingredients, due to its relatively high contribution to the overall level of the DM intake and its lower digestibility (Schulze et al., 1995). Sorensen et al. (2003) reported the amount of feces voided by pigs was dependent on dietary fiber content in diet. In this study, the DM retention from NDF was defined as the portion of cellulose and hemicellulose retained in the pig body. DM retention from carbohydrates sources in the diet therefore was estimated from retained non-structural carbohydrates, and the retained level of structural carbohydrates as follows:

$$DM\,\mathrm{Re}tEG = \beta_1 DEI + \tau NDFIT, \qquad (5\text{-}8)$$

where NDFIT is the neutral detergent fiber intake from the diet. τ is the digestibility coefficient of cellulose and hemicellulose in NDF.

ASPB is the daily amount of ash retained in pig body in grams per day. An average value of 2.25 percent is suggested for the percentage of ash in the pig daily body weight gain by the experimental data (Park, 2003). Therefore, the amount of daily ash intake that can be absorbed by pigs in gram per day was estimated as:

$$ASPB = 0.0225 DBWG, \qquad (5\text{-}9)$$

where ASPB is the amount of ash in the animal daily body weight gain (DBWG).

Total digested dry matter from digested dietary protein, carbohydrates, and ash was estimated by the following prediction model:

$$DM\,\mathrm{Re}t = WBPG + \beta_1 DEI + \tau NDFIT + 0.0225 DBWG. \qquad (5\text{-}10)$$

Using the experimental data on swine feeding trials (Carter et al., 1999; 2000, 2001; 2003), the DM retention from DE intake requirement and the digestibility coefficient of NDF (in percentage of total NDF intake) estimated by the recorded dry matter retention and protein retention as well as the estimated amount of ash retention were as follows:

$$DM\,\mathrm{Re}t = \underset{(0.0018)}{0.195}DEI + \underset{(0.0694)}{0.0996}NDFI, \qquad R^2 = 0.88. \tag{5-11}$$

The estimated standard error is shown in the parentheses. The digestibility coefficient of NDF was assumed not to vary across different feed sources. Given constant digestibility coefficients for NDF, the effect of indigestible NDF content of diet on the dry matter excretion was assumed to be due to the higher intake of total NDF. Substituting the estimated parameters for the daily amount of DM retention from DE intake requirement and digestible NDF in the diets, the prediction model for the total DM retention is:

$$DM\,\mathrm{Re}t = WBPG + 0.195DEI + 0.0996NDFIT + 0.0225DBWG. \tag{5-12}$$

DM excretion was then estimated as the difference between the calculated amount of total DM intake (DMIT) and DM retention (DMRet). The estimated amount of dry matter intake was calculated from the calculated concentrations of DM in the diet and daily feed intake level. That is,

$$\mathbf{CDMIT}_{\mathrm{d}} = \mathrm{DMContC}_{\mathrm{d}} \times \mathbf{DFIT}_{\mathrm{d}} + \boldsymbol{\varepsilon}_{\mathrm{d}}, \tag{5-13}$$

where $\mathbf{CDMIT}_{\mathrm{d}}$ is the calculated DM intake vector for the feeds in diet d, in grams per day; $\mathrm{DMContC}_{\mathrm{d}}$ is the calculated DM content for feeds in diet d; $\mathbf{DFIT}_{\mathrm{d}}$ (gram per day) is the amount of daily intake of each feed in diet d.

The DM content in the ingredients used in the experiments is not very different from the feedstuff nutrient table published by NRC (1998). Figure V-7 shows the null hypothesis of no difference between calculated and actual DM intake could not be rejected at the one percent level. The similarity between calculated and actual DM intake was reflected in this little difference between calculated and actual DM intake. Diet composition also affects total DM intake. Comparison of the diet with CS&SBMH with the diet of CS&SBM in Table V-7 show the DM intake was higher for diet with dietary fiber added, as expected.

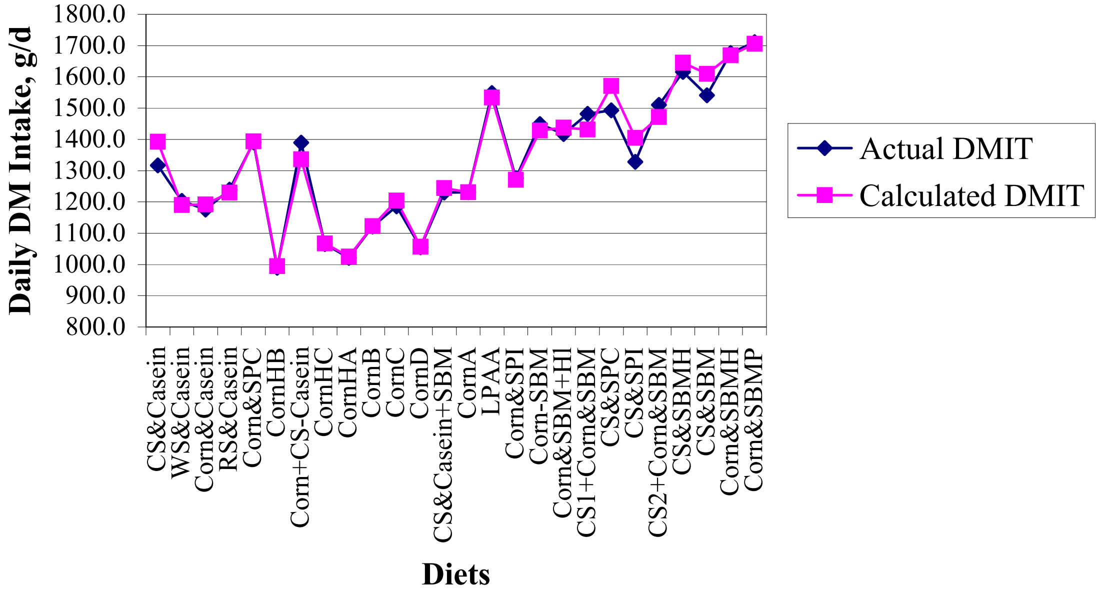

Figure V-7. The Actual and Simulated Total DM intake (DMIT, g/d) for different diets, sorted by animal body weight.

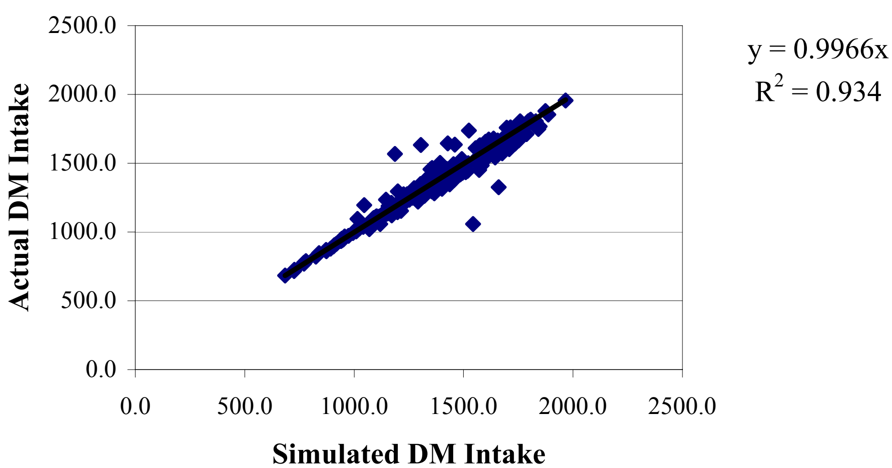

Figure V-8. The estimated relationship between actual and simulated total DM intake (DMIT), g/d.

The amount of daily dry matter excretion was then estimated by subtracting the estimated total DM retention from the actual total DM intake. A linear regression model was used to test whether the simulated DM excretion (DMExcS) was significantly different than the actual dry matter excretion (DMExc). The linear regression of the stimulated DM excretion on actual DM excretion without the intercept term was specified as

$$DMExc_t = \beta DMExcS_t + \varepsilon_t, \tag{5-14}$$

The slope parameter β is used to measure the accuracy of the simulated DM excretion. The estimated value of β was tested against one to determine whether the simulated DM excretion is different than the actual DM excretion.

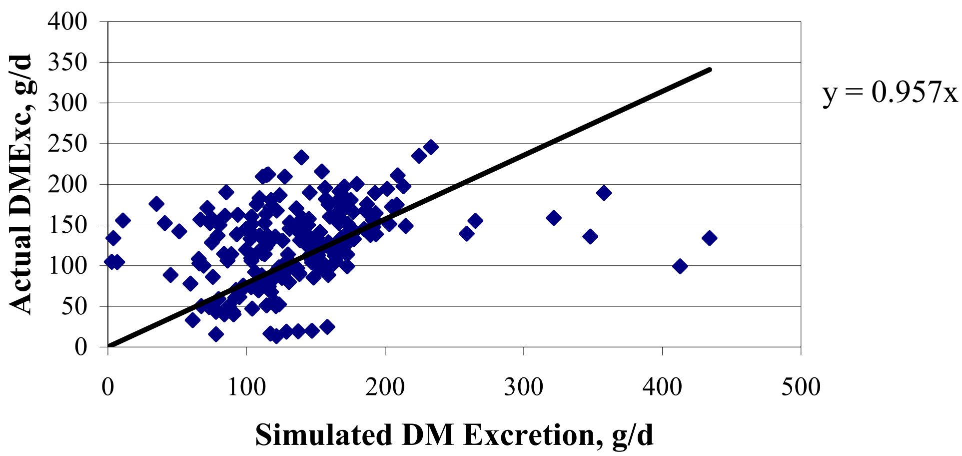

Figure V-9. The estimated relationship between actual and simulated total DM excretion (DMExc), g/d.

Figure V-9 compares the actual and simulated DM retention. The regression analysis was carried out by PROC REG (SAS Inc., Cary, NC) as shown in the equation (5-15).

$$DMExc_t = 0.957 DMExcS_t, \tag{5-15}$$

The result shows that the stimulated dry matter excretion in the manure did not differ from the actual amount at five percent significance level. The prediction model therefore performs well in estimating DM excretion.

The Simulated N, P and DM excretion model estimates the daily amount of nutrient excreted by individual fattening pigs over a growing-finishing period. Additional parameters permit the user to also account for the effect of ambient temperature, pig body weight, genotype, and growth level on total nutrient intake, and excretion. The input variables of the model are: animal initial body weight, genotype, growth level, feed intake, ration composition, ambient temperature, and fattening period. Output variables are daily amount of nutrients and dry matter excreted over a certain feeding period. The model can be used for pigs with the body weight range 20 to 110 kg. However, the diet portion has only been tested with pigs in the 20-50 kg range. In the overall profit maximization model, the prediction model via linear interpolation or extrapolation will calculate the predicted amount of nutrient excretion at nutrient intake outside the range of experiments.

The Estimation of Waste Management Cost

Concentrated swine feeding operations often have very little land for the disposal of manure. As excess manure has to be transported over large distances for use on arable land or transported to manure processing plants, it has become a major cost factor for swine feeding operations in the areas of intensive animal production.

The Decision Support System (Stoecker et al., 1998) that specifies manure management system and estimates the related costs based on the size, type, and geographic location of a swine production unit will be used to calculate waste management costs. Manure handling process in the initial spreadsheet consists of the selection of floor types and collection method in the animal house, storage and treatment methods, and land application methods. Floor Types in the animal house include fully slated, partially slated, and slab floors. Three possible manure collection methods are pit recharge, flushing, scraper, and pull plug. Decisions on the floor type and collection method in the swine house would determine whether manure is in a liquid or a slurry form. Liquid manure can be treated using aerobic lagoon, anaerobic lagoon, aerated two-cell lagoon, partly aerated lagoon, facultative lagoon, and stratified lagoon. Slurry manure can be stored in earthen storage pond, concrete above ground tank, underground tank, glass lined tank, liquid-solid earthen storage pond, and liquid solid separation concrete ground tank. After storage and treatment, manure can be applied to cropland by irrigation with a traveling gun, haul with a tanker wagon, or drag hose application. If the representative farm contained an insufficient amount land for application, it was assumed that manure that exceeds the amount that can be applied to cropland would be hauled from the farm at a cost. The relevant nutrient constraint, either nitrogen or phosphorus will depend on the type of soil and on the current legislation for that location.

In this section, we will estimate the effect of variable growth levels, and the amount of N and P excreted on the management costs, size and construction costs of manure treatment facilities, and on the fertilizer value of manure applied to crops in the district of Panhandle, OK (semi-arid whether conditions) under two different environmental constraints. The animal operation studied is a growing-to-finish operation with one-time possible pig capacities of 4,000, 10,000 and 16,000. As the planted area of dry land wheat and sorghum was 1430,000 and 258,000 acres, respectively in the district of Panhandle (Oklahoma Statistical Service, NASS), main nutrient removing crops were assumed to be dry land wheat and sorghum.

Carreira et al. (2000) tested the combinations of manure handling components for a representative farm with capacity of 2,000 to 16,000 pigs in both semi-arid and humid locations under the assumption that farm purchases pig monthly, and each animal stays in the farm a period of four months. They found that for dryland farms in a semi-arid location (Texas County, OK), the manure handling system that combined fully slated floor, pull plug, anaerobic lagoon, and effluent application with a traveling gun achieved the lowest cost per pig space for swine farm with animal capacities greater than 6000 animal spaces under the nitrogen constraint. The manure management system of fully slated floor, pull plug, anaerobic lagoon, and irrigation with a traveling gun also performed the best in terms of cost per animal space in the representative farm in Texas County for all the capacities tested under the phosphorus constraint.

This study will use feeder pigs to finishing swine operations (Oklahoma Panhandle, OK defined by Carriera). These representative swine operations were assumed to have a capacity of 4,000, 10,000, and 16,000 pigs at any point in time. Dry land wheat and sorghum were assumed to be the nutrient removing crops (Oklahoma Statistical Service, NASS). The net cost from manure management and crop production in the continuing swine feeding operation can be expressed as:

$$MCR = FV - TMC, \tag{5-16}$$

where TMC and FV are the net present value of total manure management cost, and manure fertilizer value, respectively.

The total manure management cost consists of costs for in-house management, storage and treatment, field application, and haul-off for the lifetime period of swine operation. Specifically, the total manure management cost is:

$$TMC = HC + STC + APC + HOC, \tag{5-17}$$

where TMC is the total manure management cost of the swine feeding operation. HC is the in-house management cost. STC is the storage or treatment cost. APC is the land application cost. HOC is the hauling away cost. All are in dollars for the lifetime period of swine operation.

The least cost manure management system involves fully slated floor in animal house, removing manure from the house by the manner of pull plug, storing manure with anaerobic lagoon, and applying manure to cropland by irrigation with a traveling gun. The total cost of building a fully slated floor animal house, and removing manure from the house by the manner of pull plug was estimated by DSS for each capacity (4,000, 10,000, and 16,000 animal spaces). The net present value (NPV) of total in-house manure management cost, which included initial building construction cost and annual energy, maintenance and repair cost with very large rotations of fifteen years are shown in the Table V-2.

Table V-2. Cost of manure collection for the capacity of 4,000, 10,000, and 16,000 pigs.

Collection-fully slated flooring & pull plug	Cost
4000 head	$978,849
10,000 head	$2,417,911
16,000 head	$3,871,817

Similarly, the net present value of total anaerobic lagoon cost (LGC), which includes initial construction, land, and annual maintenance and repair cost was estimated by the DSS as follows:

$$LGC = 30675 + 0.0798LGS, \qquad R^2 = 1. \tag{5-18}$$

where LGC is the net present value of the lagoon cost, in dollars. LGS is the lagoon size in cubit feet, which is determined by the volatile solid content in fresh manure as well as the number of pigs on farms. The net present value of total anaerobic lagoon cost involved a fixed cost ($30675) and a variable cost, which increased with increase in the lagoon size.

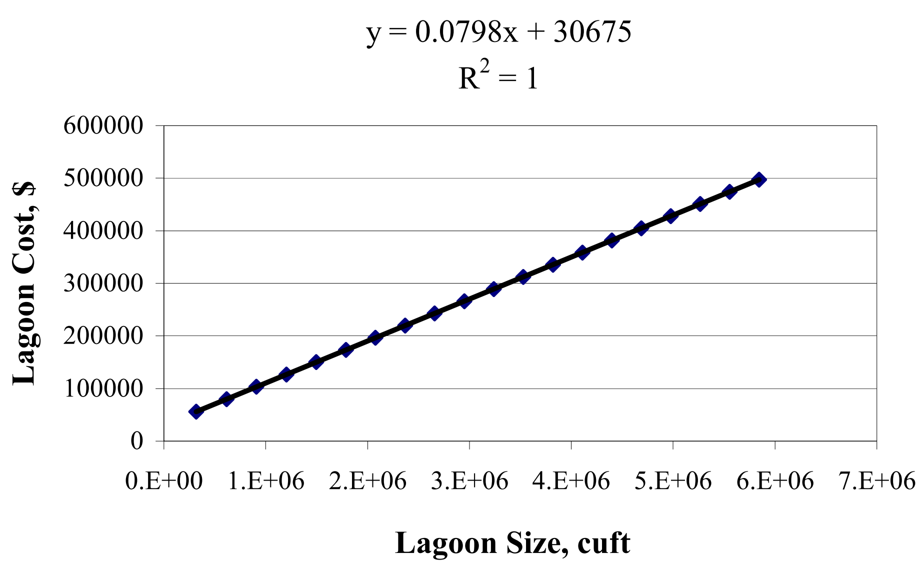

Figure V-10. The estimated relationship between the total cost and size of anaerobic lagoon size (cuft).

The anaerobic lagoon-sizing criterion depends most directly on the quantity of volatile solids excreted in the manure. The relationship between the size of lagoons for storage and treatment (LGS) and the daily amount of volatile solids (VS) in manure was estimated with the information provided by DSS (Stoecker et al., 1999) as:

$$LGS, cuft = 39919 + 613.37VS. \quad (5\text{-}19)$$

Figure V-11 shows anaerobic lagoon size (cuft) and manure volatile solids excretion (VS, lb/d) exhibited a perfectly linear relationship. The amount of volatile solids in the manure can be estimated in two steps (Ancev, 2000). First, the daily amount of DM excretion estimated using experimental data on DM intake and excretion in the last section represents a fairly good approximation for the total solids content of manure. Secondly, volatile solids can then be derived using a conversion chart of total to volatile solids provided in the Field Handbook of Waste Management-USDA. Equation (5-20) below describes how fresh dry matter excreted can convert into the volatile solid value in the manure.

$$\text{VS (lb/day)} = 0.776 \times \text{TS (lb/day)}, \quad (5\text{-}20)$$

where VS and TS are the volatile and total solid values in the manure, respectively, in lb per day. Reduction in the size of treatment lagoon in response to the dietary modifications could incur a lower waste management cost to farm.

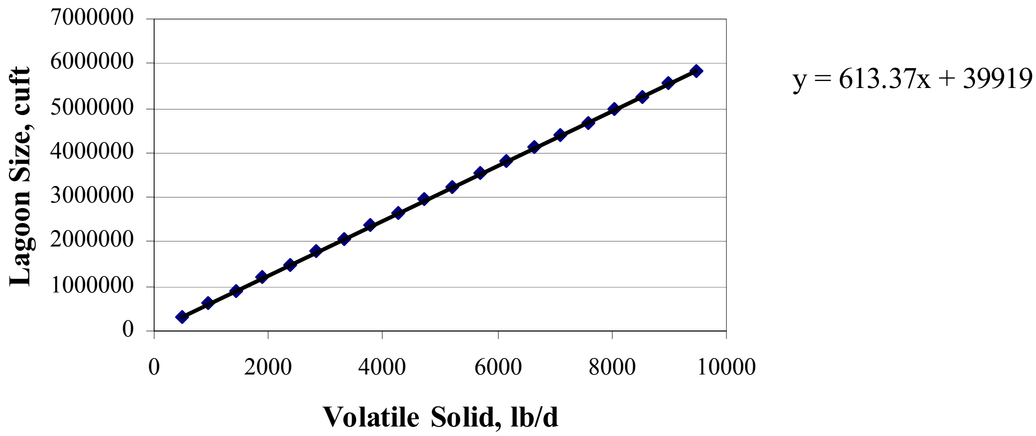

Figure V-11. The estimated relationship between anaerobic lagoon size (cuft) and manure volatile solids excretion (VS, lb/d).

The net present value of manure application cost by irrigation with a traveling gun continually every year can be specified as

$$APC = \alpha + \varpi L_j, \qquad (5\text{-}21)$$

where ϖ is the net present value of the unit application cost with a traveling gun for the very large rotations of fifteen years in dollar per acre. L_j is number of acre of cropland j that receives manure.

Waste irrigation systems may apply only 1" to 2" per acre once a year, so crop water requirements were not considered (Livestock Waste Facilities Handbook, MWPS). For a given volume of waste the irrigation unit cost ϖ is therefore less dependent on the size of lagoon liquid irrigation systems and is more affected by the time the producer spends spreading wastes. The estimated net present value of application cost in dollar for large rotations of fifteen-year periods of swine operation by DSS was

$$APC(dollar) = 12510 + 218.3 \times L_j, \qquad R^2 = 0.99. \qquad (5\text{-}22)$$

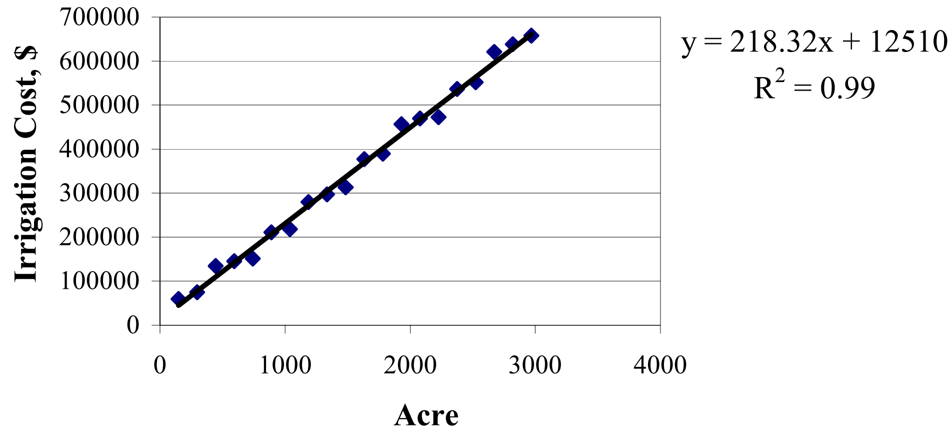

Figure V-12. The estimated relationship between land application cost (dollars) and acres receiving manure.

If the amount of available land for manure application in the swine farm was insufficient, it was assumed that the excess manure must be hauled from the farm at a base charge rate of \$0.4178/gal. The haul-off cost therefore is

$$\begin{aligned} HOC &= \upsilon \times MS \\ &= 0.4178MS \end{aligned} \tag{5-23}$$

MS is the surplus manure (in gallon), which is defined as the total manure produced minus the total amount of manure applied to crops. The variable υ is the unit haul-off cost per gallon of lagoon liquid for the infinite periods of waste management program.

Nutrient Application Restriction: Land application of manure is subject to the Nutrient Application, Manure Utilization, and Applicable Land Restrictions. The manure application rate was restricted to not exceeding the annual nutrient needs of individual crops under the relevant nutrient constraint. Under the N constraint, the N supply from manure application must be less than the amount of uptake by crop for N:

$$0.65 \times \varphi_n MA_z \leq \theta_{nz} L_z \qquad n = N,\ z = s \text{ or } w. \tag{5-24}$$

where the variable φ_n is the concentration of nutrient n in lbs per cuft of lagoon liquid, while θ_{nz} is the amount (pounds) of nutrient n requirement per acre for crop z. MA_z is the amount of liquid manure applied to the acres that produce crop z. z includes dry land sorghum (s) or wheat (w), the principal crops grown in the Panhandle district. L_z is the acres of land that were used to grow crop z.

Much nitrogen in lagoon effluent consists of decomposable N compounds that can be easily lost to the air as ammonia. In the Panhandle district where weather is usually dry, warm and windy, nitrogen loss as ammonia following land application is expected to be great. Available N level of manure for fertilizer usage was also affected by the method of application, especially when manure is irrigated by a traveling gun system that does not immediate incorporate the manure into the soil. The default was used nitrogen loss by traveling guns of 35 percent. The N level available for crop nutrient needs after application is 65 percent of the N in the lagoon liquid as shown in equation (5-24).

If manure were applied at rates designed to supply enough nitrogen requirements, the amount of phosphorus in applied manure would be considerably greater than the amount removed in harvested crops (Fact Sheet-2249, Oklahoma Cooperative Extension Service). That is, if manure were applied at rates designed to supply enough nitrogen requirements, the amount of phosphorus in applied manure would be more than the amount required by nutrient removing crops. The excess P can be described as:

$$\varphi_p MA_z \leq \theta_{pz} L_z + S_{pz}, \qquad z = s \text{ or } w. \tag{5-25}$$

where S_{pz} is the amount of P contained in manure greater than the crop needs, in pounds per acre. A similar approach can be applied to the P constraints.

Plant nutrient uptake per acre, θ_{nz} (in pounds), was based on data in the Decision Support System. Plant uptake of each nutrient was calculated according to the yield characteristics for Texas County, Oklahoma. The DSS (page CropN , cell M&) indicates that one pound of grain sorghum removes .0036 lbs of P. The average historical yield values of dry land sorghum and wheat in the Panhandle district during 2000 to 2004, 40.5 and 30.4 bushel per acre, respectively, were used to estimate the yield goal of crops, Y_z (Oklahoma Statistical Office, NASS). A grain sorghum yield of 40.5 bushels per acre at 56 lbs per bushel would require 8.165 lbs of P. However, the requirements are in lbs of P_2O_5. There is one pound of P in 2.29 lbs of P_2O_5. Thus the amount of P_2O_5 required per acre for grain sorghum would be (8.165)(2.29) or 18.7 lbs. Similarly, the amount of nitrogen required per acre for grain sorghum would be 38 lbs. Under the N (P) constraint, the surplus of nutrient N (P) must be zero. When land application was based on crop nitrogen requirements, the amount of phosphorus in applied manure would be greater than the amount removed in harvested crops result in phosphorus buildup in the soils. When the manure application rate was based on P, the N supplied by manure will be less than the amount that crops need. Supplementation with N fertilizer is therefore necessary if the manure application rate is restricted based on P.

Table V-3. Nutrient Removal by the Principal Crops in Panhandle, OK

Crop	N (lbs/bu)	P_2O_5 (lbs/bu)	N (lbs/acre)[a]	P_2O_5 (lbs/acre)
Sorghum	0.935	0.462	37.88	18.70
Wheat	1.248	0.852	37.94	34.50

Source: The Decision Support System, page CropN.

[a] The average historical yield values of dry land sorghum and wheat in the Panhandle district during 2000 to 2004, 40.5 and 30.4 bushel per acre, respectively, were used to estimate the yield goal of crops (Oklahoma Statistical Office, NASS).

In the swine growth simulation model, in which growth and feeding levels are variables, diet manipulations influence the nutrient composition and turnover of manure. The concentration of CP and P in the diet affects the daily amount of N and P excreted in manure, and thereby the N and P content in lagoon liquid. A decreased dietary CP and P content reduced the daily amount of N and P excretion in the fresh manure, as shown in the existing research (Carter et al., 2003; Crocker et al., 2002). The N and P content in lagoon liquid then decreased when the nutrient content of manure removed from the animal house decreased. To measure the effect of changing the amount and composition of nutrients in the diets used for growing pigs on the nutrient content of manure after lagoon treatment, we will first discuss the dynamic nutrient decomposition or losses in anaerobic lagoon. According to the Livestock Waste Facilities Handbook (MWPS, 1993), 70-85 percent of nitrogen can be lost to the air as ammonia from liquid lagoon system. Up to 80 percent of the phosphorus in lagoons can accumulate in bottom sludge and is not applied to land unless the sludge is removed (Livestock Waste Facilities Handbook, MWPS). The dry matter content was generally reduced from 17 percent to 1 percent after lagoon treatment. We assume that the N and P_2O_5 content of lagoon liquid could be predicted from the N and P excretion in the animal house. The annual N and P in manure as produced at animal houses could be estimated by the simulation model for the growing-to-finish period. After handling and storage, the approximate N and P_2O_5 value of manure from lagoon system are 20 percent of raw N and P_2O_5 excretion, as 80 percent of nitrogen and phosphorus in lagoons can be lost to the air as ammonia from liquid lagoon system or accumulate in bottom sludge, not applicable to land. The N and P content of manure after lagoon storage and treatment were therefore 20 percent of the N and P values at the moment it is produced by the animal. Specifically, the following equations were used to quantify the relationship between the nutrient content in fresh manure and that in lagoon liquid:

$$\varphi_n = 0.2 \times NCH / LGS,$$

$$\varphi_p = 0.2 \times 2.29 \times PCH / LGS, \tag{5-28}$$

where φ_n and φ_p are the N_2 and P_2O_5 content in lagoon liquid, respectively, in pounds per cuft. NCH and PCH are the annual N and P excretion in the animal house, respectively in lbs. LGS is the lagoon size (in cubit feet).
The daily N and P excretion were estimated with total dietary nutrient intake and retention as discussed in the previous sections. NCH (PCH) was calculated as the annual amount of N_2 and P_2O_5 produced in the animal houses.

Manure Utilization Identity- The total amount of liquid manure produced annually in the anaerobic lagoon is equal to those applied to the croplands and the manure remained after land application. That is,

$$\text{TM} = \text{TAM} + \text{MS},$$

$$\text{TAM} = \sum_{z} \text{MA}_z, \tag{5-26}$$

where z is the nutrient removing plants, dry land sorghum and wheat. TM is the total amount of manure produced annually in the lagoon in gallon for the swine feeding operation with the capacity of 4,000, 10,000 or 16,000 pigs. TAM is the total amount of manure applied to crops, in gallon. MA_z is the amount of liquid manure applied to the acres that produce z crop. The total amount of manure applied will dependent on the nutrient content of manure, expected crop removal of nutrients, and the relevant nutrient constraint. MS is the surplus manure in gallon, which must be hauled away.

Cropland Restriction- The number of acres receiving manure is equal to or less than number of tillable acres on the farm. That is,

$$\sum_{z} L_z \leq TL. \tag{5-27}$$

The land area receiving manure was bounded by tillable land owned and leased by the farm (TL). The average cropland in acres per farm according to the estimation with the data in the 2002 Oklahoma Census of Agriculture of Texas County was 834 acres. This was used to represent the available cropland of the representative swine feeding operation. It was assumed that swine operations pay to have their excess manure remove from farm to comply with manure application restrictions, if the available cropland is inadequate.

The value of manure as a fertilizer represents a revenue and is an increasing function of land availability and quantity of manure. Mathematically, the net present value of manure fertilizer value (FV) under the P restriction can be expressed as:

$$FV = \sum_{z} (0.65 \cdot P_n \varphi_n + P_p \varphi_p) \times MA_z / r \qquad z = s \text{ or } w. \tag{5-29}$$

where P_n and P_p are commercial fertilizer prices. The variable r is the annual interest rate, which was assumed to be 8 percent in our study.

The NPV of net manure management cost that included in-house management, storage, application, and haul-off costs minus manure fertilizer value was then

$$
\begin{aligned}
MCR &= FV - TMC \\
&= \sum_z (0.65 \cdot P_n \varphi_n + P_p \varphi_p) \times MA_z / 0.08 - HC - \\
&\quad [30675 + 0.0798 \times (39919 + 476TS)] - \\
&\quad (12510 + 218.3L_j) - 0.42MS,
\end{aligned} \tag{5-30}
$$

subject to the restrictions of nutrient application, manure utilization, and land availability.

A lower proportion of N and P in manure may have a negative influence on the fertilizer value of manure in the field. The lower plant availability of manure N and P due to dietary manipulation and nutrient losses in storage and treatment stage will incur higher application cost.

Crop prices used were the average Oklahoma monthly prices in 2001 to 2004: \$3.66/bu for sorghum, and \$3.07/bu for wheat (USDA, 2005). Fertilizer nutrient prices excluding application costs were \$0.18/lb for nitrogen, and \$0.19/lb for phosphorus (Stoecker et al, 1998). Phytase-supplemented feed was assumed to increase digestible P for growing pig by 6.3, 12.7, 19.0 and 25.3 percent with 250, 500, 750 and 1000 PU of phytase at a cost of \$1.054 per pound of additional available P (Boland et al., 1998).

Integrated Ration Formulation

The purpose of this section is to determine the profit-maximizing ration that would satisfy specific nutrient requirements with respect to overall optimal production level that incorporates waste management factors into consideration for a typical hog feeding operator with the capacity of 4,000, 10,000, and 16,000 growing pigs. The modified simulation model presented in Chapter IV will be used as a basis for the problem of economic optimization. Suppose the goal of the swine feeding operation was to maximize profit per pig from an infinite number of continuous production cycles under carcass merit pricing programs. The operation produces only feeder-to-finishing pigs.

The selected type of manure management system is fully slated floor animal houses, pull plug, anaerobic lagoons, and field irrigation with a traveling gun. Similar to Chapter II, the system-level constrained profit maximization problem that considered gross revenue, feeding cost, and waste management cost simultaneously was stated as

MAX

$$ZV = \Omega \times [(Pb \times U \times FBW)/(1+d)^{T\text{-}1} - \sum_{1}^{T} C_t/(1+d)^{T-1} - C_f] + MCR/nb, \quad (5.3\text{-}1)$$

(capital recovery factor × (pork basis price × carcass merit system index × final body weight/discount factor less total discounted feed costs less fixed cost)-lifetime manure management cost)

with respect to T, y_{jt}, *and* BW_t

subject to

$$\sum_{1}^{J} E_j \times Y_{jt} \geq DEI_t \quad (5.3\text{-}2)$$

(The DE content in the rations)

$$EXP(-17.8RANI_t + 11.5RANI_t^2 + 1.8RANI_t \times DET_t + 2.2DET_t - 0.4DET_t^2) \times 13162[1\text{-}\exp(-0.0176BW_t)] \geq DEI_t$$

(The upper bound of DE intake) (5.3-3)

$$110 \times \mathrm{BW}_t^{0.7} \leq \mathrm{DEI}_t \quad (5.3\text{-}4)$$

(The lower bound of DE intake)

$$EAA_t(i) = 0.036 \times BW_t^{0.7} \times AAm(i) + 0.12 \times WBPG_t \times AAp(i) \quad (5.3\text{-}5)$$

(Total essential amino acid requirement for maintenance and protein growth)

$$\sum_{1}^{J} A(i,j) \times B(i,j) \times Y_{jt} \geq EAA_t(i) \quad (5.3\text{-}6)$$

(The amino acid content in the rations must be at least equal to what is required)

$$TNIT_t = \sum_{1}^{J} N(j) \times Y_{jt} \quad (5.3\text{-}7)$$

(Total N content in the ration)

$$TPIT_t = \sum_{1}^{J} H(j) \times Y_{jt} \quad (5.3\text{-}8)$$

(Total P content in the ration)

$$PHR_t = EXP(4.7 - 21.8RAPI_t + 34.4RAPI_t^2 - 18.2RAPI_t^3) \times (EXP(-0.0557\text{-}0.416 \times \ln BW_t + 0.005 \times \ln BW_t^2)/100) \times 0.3255DEI_t \quad (5.3\text{-}9)$$

(The phosphorus retention equation, adjusted by dietary nutrient content)

$$\sum_1^J O(j) \times H(j) \times Y_{jt} \geq EXP(4.7 - 21.8RAPI_t + 34.4RAPI_t^2 - 18.2RAPI_t^3) \times (EXP(-0.0557\text{-}0.416 \times \ln BW_t + 0.005 \times \ln BW_t^2)/100) \times 0.3255DEI_t \quad (5.3\text{-}10)$$

(The phosphorus content in the rations must be at least equal to what is required)

$$\sum_1^J CA(j) \times Y_{jt} \geq (EXP(-0.0658\text{-}0.1023 \times \ln BW_t\text{-}0.0185 \times \ln BW_t^2)/100) \times (1250 + 188 \times BW_t - 1.4 \times BW_t^2 + 0.0044 \times BW_t^3)/3.4 \quad (5.3\text{-}11)$$

(The calcium content in the rations must be at least equal to what is required)

$$\sum_1^J O(j) \times H(j) \times Y_{jt} / \sum_1^J CA(j) \times Y_{jt} = 1.9 \quad (5.3\text{-}12)$$

(The ideal ratio of phosphorus to calcium in the ration)

$$C_t = \sum_1^J P_j \times Y_{jt} \quad (5.3\text{-}13)$$

(The feed cost)

$$WBPG_t = (1 - EXP(1.5474RAEN_t - 70.6212TNCont_t - 88.5874RAEN_t \times TNCont_t)) \times (17.5e^{-0.0195BW_t} + 16.25) \times 0.003137MFFL \times 0.94DEA_t$$

(The whole body protein generating equation, adjusted by dietary nutrient content) (5.3-14)

$$PTG_t(g) = WBPG_t / 0.23$$

(The daily protein tissue gain) (5.3-15)

$$LP = (IFFL + \sum_1^T 2.55 \times WBPG_t)/(1000 \times FBW/1.35) \quad (5.3\text{-}16)$$

(The lean percent in the carcass)

$$FSY_t = (0.96 \times DE - 10.6 \times WBPG_t - 106 \times BW^{0.75})/12.5 \quad (5.3\text{-}17)$$

(The daily lipid synthesis from energy intake)

$$FTG_t = FSY_t / 0.9 \quad (5.3\text{-}18)$$

(The daily fat tissue gain)

$$DBWG_t = (PTG_t + FTG_t)/0.94 \quad (5.3\text{-}19)$$

(The daily body weight gain)

$$BW_{t+1} = BW_t + DBWG_t \tag{5.3-20}$$

(The body weight accretion equation)

$$FBW = 20 + \sum_1^T DBWG_t \tag{5.3-21}$$

(The body weight at the marketing day)

$$MCR = FV - HC - [30675 + 0.0798 \times (39919 + 476\sum_t DMExc_t / T)] - (12510 + 218.3L_j) - 0.42MS$$

(Net revenue from manure management) (5.3-22)

$$F_{nz} + 0.65 \times \varphi_n MA_z \text{-} \theta_{nz} L_z - S_{nz} = 0,\ n = P,\ z = s\ or\ w. \tag{5.3-23}$$

(Nutrient application restriction)

$$TAM + MS = 39919 + 476\sum_t DMExc_t / T \tag{5.3-24}$$

(Manure utilization identity)

$$TAM = \sum_z MA_z \tag{5.3-25}$$

(Total volume of manure applied, in cuft)

$$\sum_z L_z \le 834. \tag{5.3-26}$$

(Cropland restriction)

$$NExc_t = TNIT_t - \sum_{Lys}^{Val} N_i \times EAA_t(i) + (1/6.25) \times (WBPG_t - \sum_{Lys}^{Val} EAA_t(i)). \tag{5.3-27}$$

(Total daily N excretion, in lb per day)

$$PExc_t = PIT_t \text{-} PHR_t. \tag{5.3-28}$$

(Total daily P excretion, in lb per day)

$$DMExc_t = DMIT_t - (WBPG_t + 0.195DEI_t + 0.0996NDFIT_t + 0.0225DBWG_t). \tag{5.3-29}$$

(Total daily DM excretion, in lb per day)

$$\varphi_n = 0.2 \times NCH / SLG. \tag{5.3-30}$$

(The N content in lagoon liquid)

$$\varphi_p = 0.2 \times 2.29 \times PCH / SLG. \tag{5.3-31}$$

(The P content in lagoon liquid)

where ZV is the value of the objective function, expressed in life time discounted profit per pig; Ω is the approximate capital recovery factor; P_b is the base hog price per kg; and $U(\cdot)$ is the net carcass quality premiums (discounts) rates expressed as the percentage of base hog price for desirable (undesirable) carcass traits; FBW is the final body weight; C_t is the variable cost of feed intake sequence over the feeding period, which is dependent on the desired growth path; C_f is the fixed cost of feeder pigs; MCR is the life-time crop net return from acres receiving manure, which also represented the cost associated with nutrient excretion. A(i, j) represents the *i*th essential amino acid content of feed ingredient j B(i, j) is the coefficient for true digestibility of amino acid i in feed ingredient j; N(j) is the total N content in the *j*th feed ingredient; O(j) is the coefficient for bioavailability of phosphorus in feed ingredient j; H(j) is the total phosphorus content in the *j*th feed ingredient; CA(j) is the calcium content in feed ingredient j; P_j is the price of jth feed ingredient. AAm(i) and AAp(i) are twelve-element vectors containing the requirement profile of essential amino acid for maintenance and protein growth, respectively. DEI_t is the digestible energy intake at day t. The variable nb is the number of hogs, or the hog capacity,

The carcass weight-pricing program that assigned premium (discount) on the prices of pigs with desired (undesired) fat free lean fraction in carcass and final body weight was estimated in the Chapter III. The amino acid and phosphorus concentration of feed ingredients and requirements in the setting of the nutritional constraints were expressed in true ileal digestible basis rather than in crude units to more precisely represent the ingredients' nutritional values and the animal nutrient requirements. The total N and P intake were expressed in crude units, which included the digestible fractions as well as indigestible, unbalanced and excess fractions of N and P intake. As described in the last section, the amount of N (P) excreted in the manure was calculated from the total amount of N (P) intake minus the amount retained by the animal. The estimated N (P) excretion corresponded to the indigestible, unbalanced and excess fractions of nutrient intake as well as the maintenance, endogenous losses, and was used as input variable to calculate the waste management cost associate with swine production.

The decision variables available to a swine feeding operation facing a restriction where land application was limited to crop nutrient needs were assumed to be diet composition, growth level, feeding period and the number of pigs on the farm. The optimization problem involves a linear program that was used to select a profit-maximizing set of ingredient quantities subject to a series of restrictions of growth, and nutrient requirement and excretion. Ingredients are characterized and selected on basis of their price and nutritional composition that includes the digestible energy, available and total P, total N, and digestible essential amino acid contents. The diet was formulated to maximize the overall profit of swine production. In addition to feeding cost, nutrient excretion and waste management cost of a growing-finishing pig were estimated by simulating an average pig fed from 20 to 120 kg in a feeding period of T days. The profit-maximizing model was formulated in GAMS 2.5 using the MINOS solver to determine the feed rations needed to support the optimal growth trajectory. In this study, we consider the restrictions imposed on application of excreted nitrogen and phosphorus to cropland. This is accomplished by varying the number animals for a given size of farm and by limiting application to either the N or P needs of the crops.

Comparison between NRC and Lab Simulation Models

To compare farm level and controlled laboratory confined space conditions, we first analyzed the profit maximization ration formulation by assuming corn, SBM, dicalcium phosphate, ground limestone are the only available feedstuffs.

Farm Simulation Models without Nutrient Adjustment Terms

The DE intake, protein and phosphorus retention equations of initial NRC simulation model were assumed to represent the farm level conditions with traditional corn-SBM diets. These equations were employed in the over-all profit maximization model for the swine feeding operation with animal capacity of 4,000 pigs under P restriction. That is, equation (5.3-3), (5.3-8) and (5.3-14) of the system level swine profit maximization model above were replaced by the farm level growth equations without nutrient adjustment terms as follows:

$$13162[1\text{-}\exp(-0.0176BW_t)] \geq DEI_t \tag{5.3-3}$$

$$PHR_t = EXP(\text{-}0.0557\text{-}0.416\times\ln BW_t + 0.005\times\ln BW_t^2)/100\times 0.3255DEI_t \tag{5.3-8}$$

$$WBPG_t = (17.5e^{-0.0195BW_t} + 16.25)\times\ 0.003137MFFL\times 0.94DEA_t \tag{5.3-14}$$

The simulation result of initial NRC model which represented profit maximizing behavior of the swine feeding operation under farm condition was shown in column two in Table V-4 for the animal capacity of 4,000 pigs under N and P restriction.

Lab Simulation Models without Nutrient Adjustment Terms

The modified DE intake, protein and phosphorus retention equations of simulation model using the experimental data on the corn-SBM diets represented pig growth in a laboratory well-controlled metabolism chambers. The overall profit maximization model under laboratory conditions can be obtained by replacing equation (5.3-3), (5.3-8) and (5.3-14) of the profit maximization model above with the growth equations in the laboratory without the nutrient adjustment terms as follows:

$$12133[1\text{-}\exp(-0.0176BW_t)] \geq DEI_t \quad (5.3\text{-}3)$$

$$PHR_t = EXP(\text{-}0.0557\text{-}0.416 \times \ln BW_t + 0.005 \times \ln BW_t^2)/100 \times 0.3255DEI_t \quad (5.3\text{-}8)$$

$$WBPG_t = (17.5e^{-0.0195BW_t} + 27.52) \times \ 0.003137MFFL \times 0.94DEA_t \quad (5.3\text{-}14)$$

where the intercepts of DE intake and protein retention equations were adjusted with experimental data on corn-SBM diet to reflect laboratory level controlled conditions in which pigs were kept in confined spaces. Column three in Table V-4 shows the simulation result of the profit maximization model under the experimental conditions for the swine feeding operation with animal capacity of 4,000 pigs under manure application restriction.

Effects of Diets on Farm Simulation Models

The analysis in Chapter IV suggested that dietary nutritional content also significantly affected the DE intake as well as protein and phosphorus retention. To determine the effect of dietary nutrient concentration on growth variables, the modified DE intake as well as protein and phosphorus retention equation in which adjusted terms of dietary nutrient contents were included as shown in Chapter IV were used in the overall profit maximization model. Instead of re-estimated values, the intercept values recommend by NRC were used in the simulation model to exam the overall profit maximization under the farm conditions. That is, the DE intake as well as protein and phosphorus retention equations as shown in the simulation model above were used to determine the overall profit maximization for the farm conditions in which dietary nutrient concentration also significantly affected growth variables. The simulation result of estimated swine growth on farms was shown in the column four of Table V-4.

Table V-4. The optimal solution of the system-level profit-maximizing problem for swine production with 4,000 pigs under P restriction.

Item\Capacity	Initial NRC/Farm	Laboratory w/o Adj	Farm w. Adj
Feeding Period, d	89	78	94
Final Wt, kg	118.9	119.2	119.1
Lean Percent, %	49.4	58.2	49.2
Profit, \$/pig[a]	33.3	81.1	27.1
Revenue, \$/pig	103.3	158.3	96.7
Feed Cost, \$/pig	63.1	70.4	62.7
Waste Cost, \$/pig 15 yrs[b]	199.0	192.2	194.7
CLG[c], \$ 15 yrs	87306.7	65448.9	87443.6
APC[d], \$ 15 yrs	102508.3	113327.5	101823.6
HOC[e], \$	0	0	0
Acre			
Sorghum	628.6	700.9	624.0
Wheat	0	0	0
Lagoon Size, cuft	1.21×10^{6}	8.13×10^{5}	1.22×10^{6}
Manure App, cuft	1.21×10^{6}	8.13×10^{5}	1.22×10^{6}
Manure Haul, cuft	0	0	0
NCLG[f], lb/cuft	0.025	0.047	0.033
PCLG[g], lb/cuft	0.010	0.016	0.010

[a] The profit refers to the profit per pig (not including waste handling cost) in dollars for a single feeding period of 89, 78, or 94 days.

[b] The waste cost refers to the waste management cost of 15 year period in dollars per pig.

[c] The total cost of anaerobic lagoon (LGC), which includes initial construction, land, and lifetime maintenance and repair cost.

[d] The cost of application with a traveling gun for the continuing land application programs.

[e] The cost of hauling excess manure off the farm.

[f] N content in lagoon liquid.

[g] P content in lagoon liquid.

Figure V-13, 5-14, and 5-15 show the overall profit maximization level of daily feed intake as well as optimal body weight and protein growth paths. The ad labium feed intake and maximum body weight and protein growth rates were obtained from swine growth spreadsheet adopted from initial NRC simulation model as described in Chapter II.

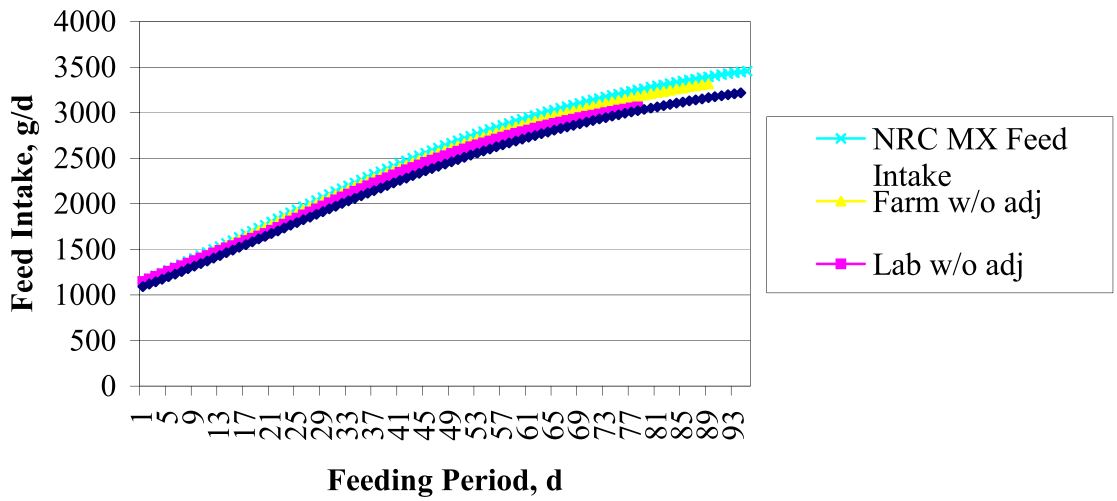

Figure V-13. The optimal feed intake (g/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment, and the predicted maximum growth with NRC model.

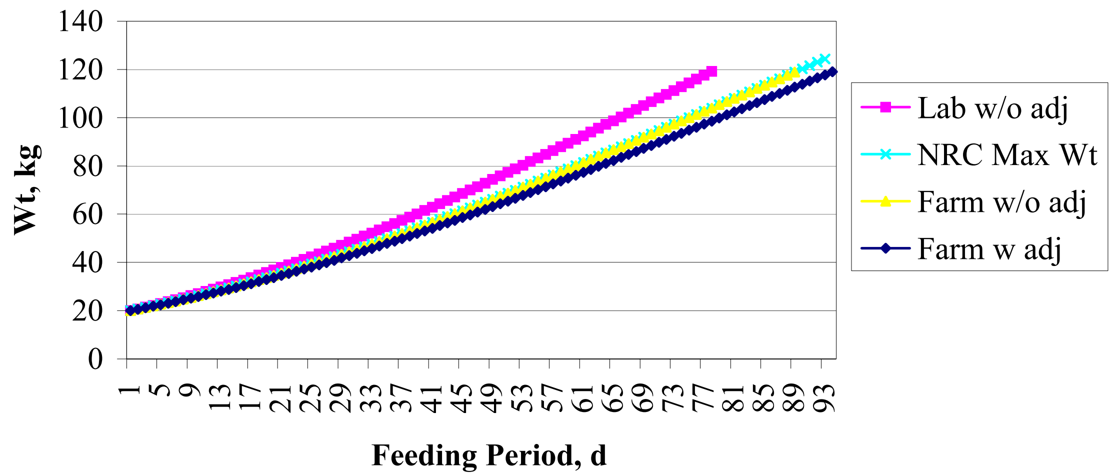

Figure V-14. The optimal growth trajectory for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment, and the predicted maximum growth with NRC model.

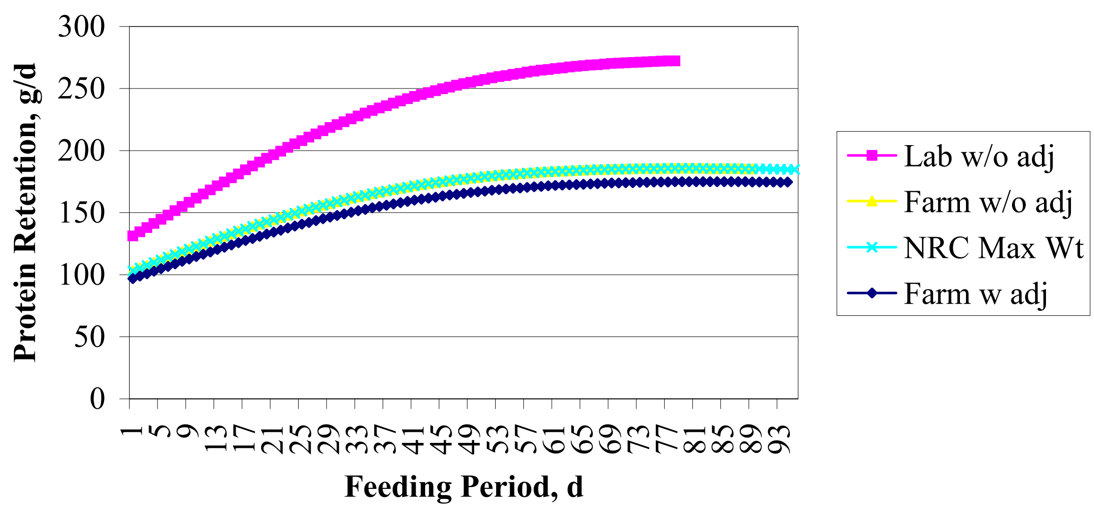

Figure V-15. The optimal protein retention (g/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment, and the predicted maximum growth with NRC model.

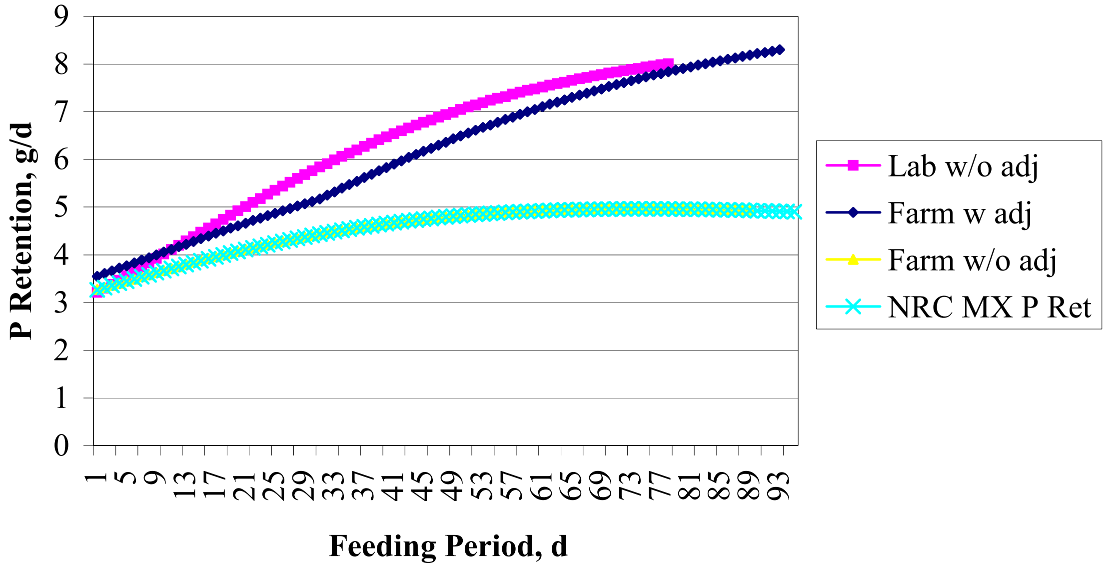

Figure V-16. The optimal P retention (g/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment, and the predicted maximum growth with NRC model.

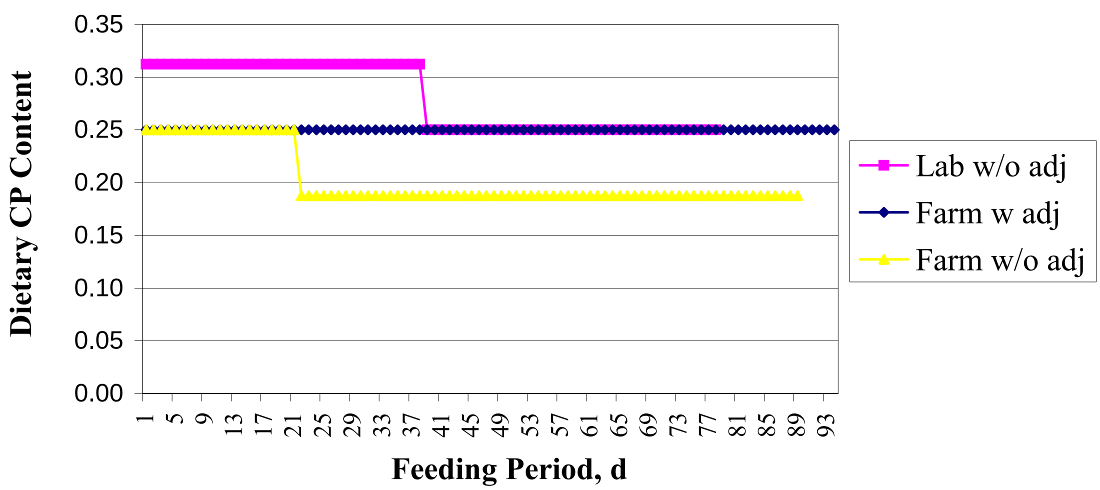

Figure V-17. The dietary CP concentration for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment.

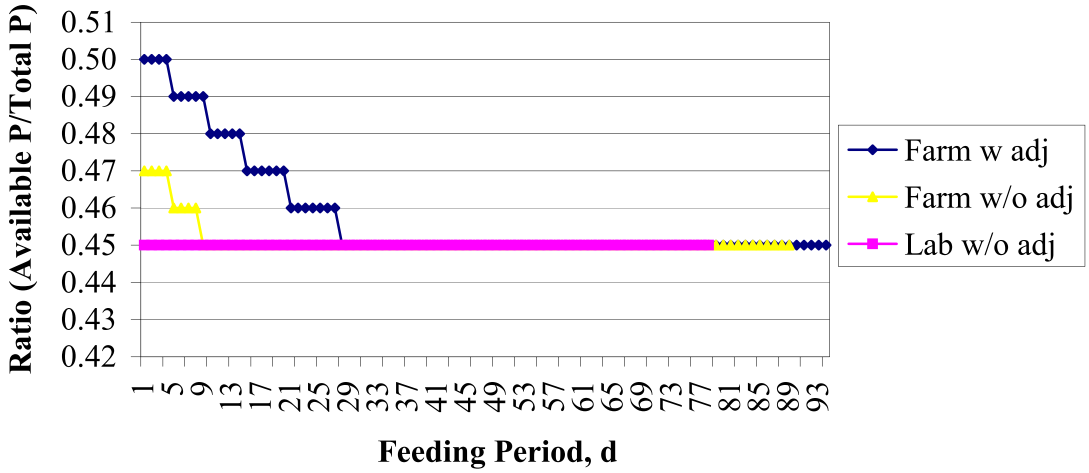

Figure V-18. The optimal ratio of dietary available P to total P for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment.

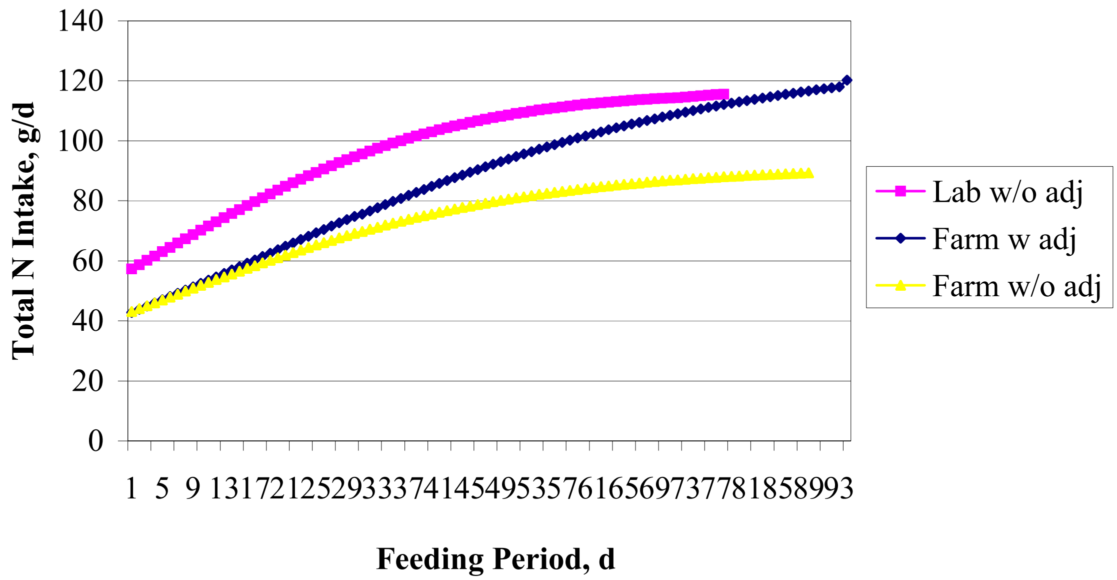

Figure V-19. The total N intake (g/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment.

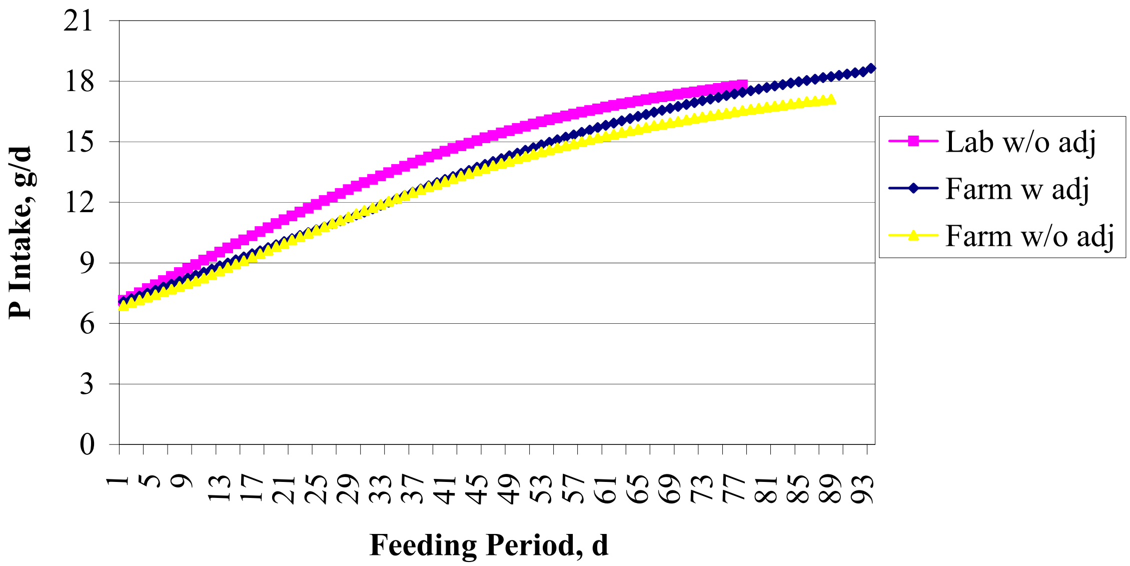

Figure V-20. The total P intake (g/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment.

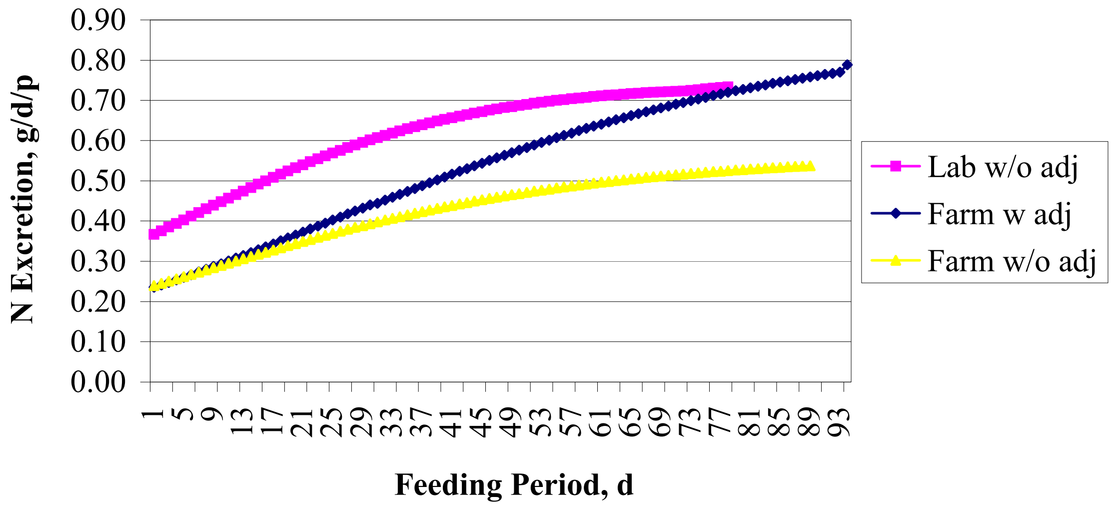

Figure V-21. The total daily N excretion per pig (lb/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment.

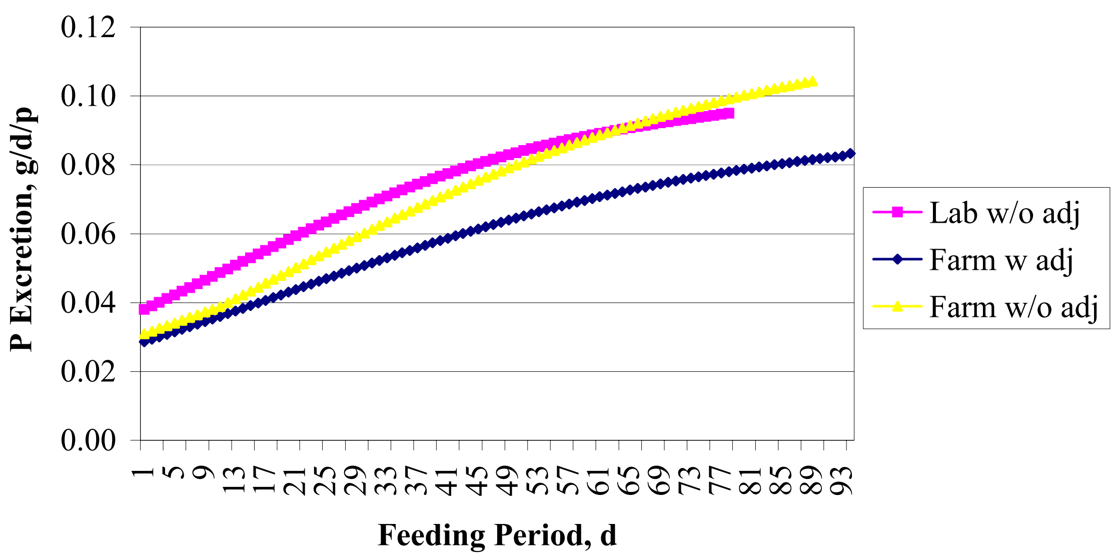

Figure V-22. The daily P excretion per pig (lb/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment.

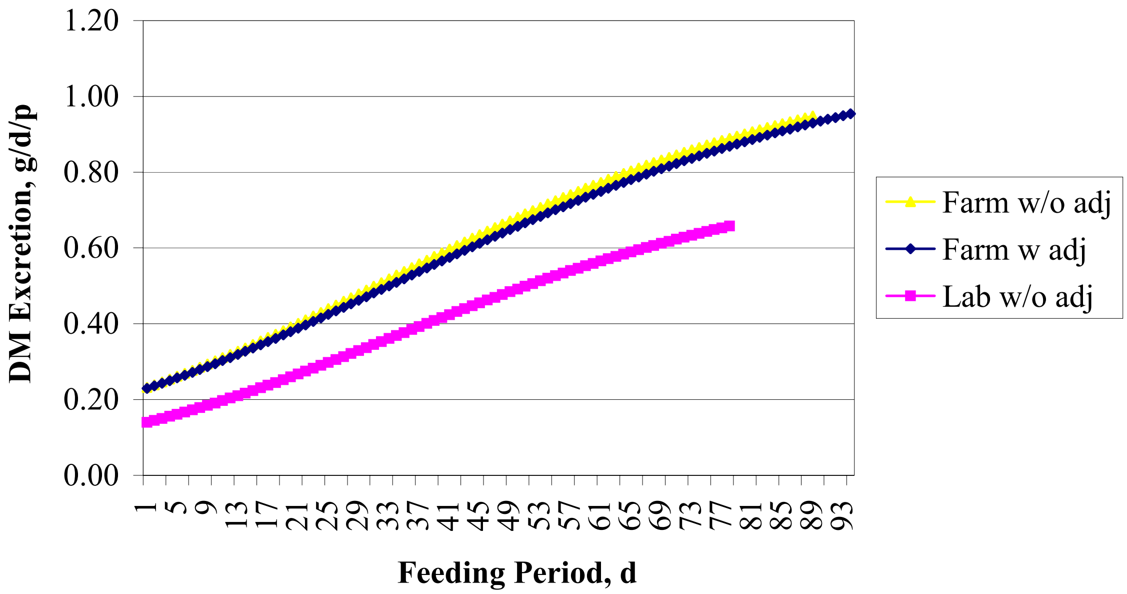

Figure V-23. The daily DM excretion per pig (lb/d) for the swine feeding operation with 4,000 pigs, simulated with lab conditions w/o nutrient adjustment, farm conditions w and w/o adjustment.

Figure V-12 shows that pigs under experimental conditions had lower feed intake but higher protein retention and body weight gain than those that were free to move around, which resulted in higher profit in the situation where pigs were kept individually in metabolism chambers. A comparison between initial NRC farm level model in which waste management components were directly accounted for and the stepwise profit maximizing model suggested that the waste handling coat, lagoon size, and required application acres were greatly reduced in the overall profit maximizing programming model, though the performance variables were little affected. Greater efficiency in swine production had been observed in the system level profit maximization swine feeding operation. As the production level in the stepwise analysis of Chapter III can not adjust with responding to waste components, waste handling capacity and cost per animal space obtained for the system level profit maximizing simulation model in which manure management components were directly accounted for were expected to be lower. As the available feedstuffs in the simulation model above were mainly corn and SBM, it would be expected that feed cost was lower in the stepwise profit maximization model of Chapter III in which available feedstuffs were more diverse. The analysis also shows the initial NRC model that did not include the adjustment terms of dietary nutrient content tended to over-estimate animal performance. Including the adjustment terms associated with dietary nutrient content in the modified feed formulation program increased the amount of N and P consumed by pig during the overall growing-finishing period, as shown in Figure V-19, and 5-20. The required dietary CP and P concentration were also higher for modified feed formulation program that included adjustment terms compared with that without the adjustment, while the feed intake was almost the same (Figure V-13 through 5-18). Incorporation of synthetic amino acids in the diets may promote the more efficient use of protein and improve the utilization of N in pig. However, previous studies have shown decreased retention of protein with decreased dietary protein content, but with a sufficient content of essential amino acids in the diet (Carter et al, 2003). When the dietary nutrient content was considered, pigs consumed and excreted more N and P to ascertain profit maximization growth level. As such, profit from pens of pigs under commercial growing conditions would be lower than that predicted by the NRC model where the effects of dietary nutrient factors were not considered. Detailed daily ration of feeds selected in each simulation model are shown in Appendix Table A5-3.

Effect of Animal Capacities under a P Restriction with Adequate Acres

Comparison in terms of animal capacities was further performed under the nutrient restriction. With the N restriction, manure application rate was restricted not to exceed the N need of each nutrient removing crop and acres receiving manure. Phosphorus is another essential element in the animal's body. In addition to its participation in the development and maintenance of skeletal tissue, it plays an important role in other metabolic function (NRC, 1998). Although feedstuffs of vegetable origin contain adequate amount of P, 66 percent of P is present as phytate and is not digestible by pigs (Jongbloed and Kemme, 1990). To obtain good performance, additional inorganic phosphorus is supplied to swine rations. As a result, the indigestible phytate P and the surplus of P supply were excreted in the manure. Most crops require about eight times as much as nitrogen as phosphorus. However, the N:P ratio of lagoon effluent is close to 4:1 (Fact Sheet-2249, Oklahoma Cooperative Extension Service). That is, if manure were applied at rates designed to supply specific crop P requirements, both the amount of N and P in applied manure would not be in excess of crop uptake requirements. Land applications based on crop P requirements would avoid phosphorus buildup and subsequent negative impact on water quality (Fact Sheet-2249, Oklahoma Cooperative Extension Service). This part of the study will focus on the analysis of the P restriction.

A diverse set of primary energy-supplying ingredients including corn, sorghum, SBM, and wheat was assumed available to the swine feeding operator. Crystalline amino acids, L-tryptophan, DL-methionine, L-lysine, L-threonine were included in the model as the supplemental protein sources. Other mineral sources, dicalcium phosphate, and limestone calcium were also assumed available in the model. The simulation result shows that in addition to traditional swine feedstuffs of corn and SBM, wheat was also selected to include in the optimal rations. It demonstrated that wheat was a main substitute feed ingredient for corn and SBM because of its excellent nutrient values and competitive price. Figure V-24 and Appendix Table A5-4 show the lower part of optimal protein retention curve corresponded to the rations with wheat replacing a proportion of corn and SBM.

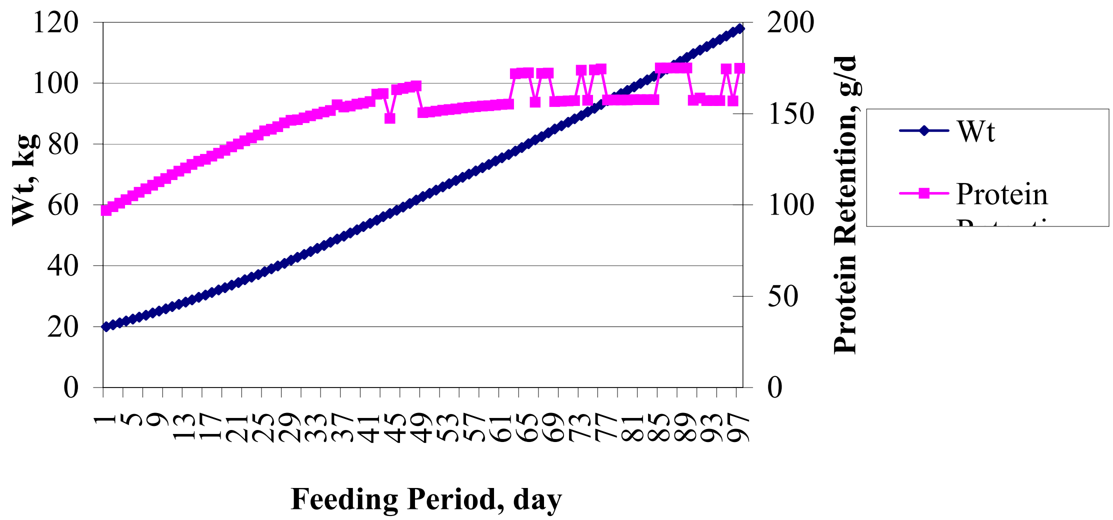

Figure V-24. The optimal body growth trajectory and protein retention for the swine feeding operation with 4,000 pigs, simulated with broadly available feed ingredients, which included wheat and adequate cropland.

To concentrate on the standard corn-SBM diet, and its interrelationship with other low CP, low P feedstuffs, the cost of wheat was arbitrarily increased to five times of its current level to make it economically infeasible. Studies with growing pigs of 20 kg live weight fed ad labitum have shown that microbial phytase may enhance the digestibility of P by more than 20 percent but also improved growth rate and feed conversion ratio (Park, 2003). It was shown that when 1000 units of phytase/kg added to the diet, that the digestibility of P increased from 44 to 70 percent. In the end of Chapter IV, an attempt had been made to quantify the influence of microbial phytase on P digestibility in the corn-SBM based diet. The effect of phytase addition on P digestibility of the diet was quantified with the following linear regression equation (4-3):

$$\text{P digestibility} = 0.461328 + 0.000253 \times \text{PU}, \quad R^2 = 0.79$$

Phytase-supplemented feed was assumed to increase digestible P for the growing pig by 0.0253 percent with one PU of phytase. In accordance with Boland et al. (1998), the cost of phytase was calculated as $1.054 per pound of additional available P. With the P restriction, manure application rate was restricted not to exceed than P need of each individual crop. The swine feeding operator may either choose to adjust production level so as to reduce the requirement of inorganic phosphorus supplement or add phytase to hog feed to reduce the P content of manure and thus the land acres needed for manure disposal.

Nutrient requirements and excretion of a growing-finishing pig as well as feeding and waste management costs were estimated by simulating an average pig fed with daily-adjusted diet until 120 kg body weight under a P restriction. In Table V-5 the estimated profit, feed cost, and manure management cost for different animal capacities were presented. In addition, Table V-5 and Figure V-25 to 5-36 show the effect of operation capacities on animal performance and feeding strategy during the growing period. From the simulation model it was calculated that animal capacity of swine feeding operation has little influence on the feed rations, growth trajectory, lean percent at slaughter, as well as N, P and DM excretion. Table V-5 shows that a swine CAFO of any size would tend to grow swine with same final body weight in a same feeding period under the restriction on P application. Similarly, animal capacities did not affect N, P and DM excretion per pig produced since N, P and DM intake and retention during the growing-finishing period was not affected by the size of swine operation. The detailed daily ration composition as shown in the Appendix table A5-5 was also little different for each animal capacity.

N and P excretion per pig increased as pigs grew. There are two main conditions underlying the increased excretion of N and P in growing pigs. First, both recommended N and P requirement and intake increased as pigs grew. Second, the CP and P utilization in pigs was low, and the dietary content of N and P was so high that pigs excreted the excessive amounts of N and P in the urine and manure. The latter indicates that the digestibility of N and P were low in the overall profit maximization diets. The concentration of CP and total P in pig diets can change very fast according to the prices of the different feedstuffs. Under the current feed price levels, available amino acid and digestible P content in economically competitive feedstuffs might be too low, with too much CP and total P. To reduce the amount of the N and P excreted, it is necessary to include highly digestible feeds in the profit maximization rations, lowering indigestible portion of dietary CP and P. The current price levels of feedstuffs with highly digestible amino acids and P must be lower so as to make high quality feed ingredients economically feasible in the profit maximization swine production model.

Table V-5. The comparison between optimal solution of the system level profit-maximization and swine waste management model under a P restriction when applicable cropland was adequate.

Item\Pig Capacity	4,000		10,000		16,000	
Model	Simulation	SWM[f]	Simulation	SWM	Simulation	SWM
Feeding Period, d	94	--	94	--	94	--
Final Wt, kg	119.1	--	119.1	--	119.1	--
Lean Percent, %	49.2	--	49.2	--	49.2	--
Profit, \$/pig[g]	26.8	--	27.0	--	27.1	--
Revenue, \$/pig	96.6	--	96.6	--	96.6	--
Feed Cost, \$/pig	63.0	--	63.0	--	63.0	--
Waste Cost, \$/pig 15 yrs[h]	194.7	296.3	188.0	291.4	186.9	291.4
CLG[a], \$/ 15 yrs	87649	102776	183789	221928	280066	340427
APC[b], \$/ 15 yrs	101687	103652	241549	274348	381342	450557
HOC[c], \$	0	0	0	0	0	0
Application Acre						
Sorghum	623.0	742.0	1558.6	1855.0	2493.5	2967.9
Wheat	0	0	0	0	0	0
Lagoon Size, cuft	1.21×10^6	1.50×10^6	2.98×10^6	3.67×10^6	4.74×10^6	5.84×10^6
Manure App, cuft	1.21×10^6	1.50×10^6	2.98×10^6	3.67×10^6	4.74×10^6	5.84×10^6
Manure Haul, cuft	0	0	0	0	0	0
NCLG[d], lb/cuft	0.033	0.004	0.033	0.004	0.034	0.004
PCLG[e], lb/cuft	0.010	0.010	0.010	0.010	0.010	0.010
PU Addition	0	0	0	0	0	0

[a] The total cost of anaerobic lagoon (LGC), which includes initial construction, land, and lifetime maintenance and repair cost.
[b] The total cost of application with a traveling gun for the continuing land application programs.
[c] The total cost of hauling excess manure off the farm. [d] N content in lagoon liquid. [e] P content in lagoon liquid.
[f] SWM = the swine waste management model developed by Stoecker et al (1998).
[g] The profit refers to the profit per pig (not including waste handling cost) in dollars for a single feeding period of 94 days.
[h] The waste cost refers to the waste management cost of 15 year period in dollars per pig.

Regardless of their size, all operations selected dry land sorghum as the nutrient-removing crop. The acres of manure fertilized sorghum increased as the size of swine feeding operation increased. The CAFOs of 10,000 and 16,000 pigs utilized more than 834 acres of average farm size in the Panhandle district to comply with the P-restriction because of a relatively higher pig-to-land ratio. However, the required cropland for application in the simulation model was lower than that required in the swine waste management model for all three capacities. As feed and waste management cost was directly considered in the system level swine feeding production, the acres required in the integrated profit maximization problem were less than that required by the swine waste management model, in which waste management cost was minimized given the production levels. With the assumption that applicable land for the total volume of manure was adequate, the swine feeding operation of any size did not generate excess manure that need be hauled off the farm. As available acre for land application was adequate, the economic impact of the manure disposal on pig production was greatly reduced. The system becomes less sensitive to feeder pig capacity because the cost to haul manure from the farm was not present. Results on the effects of animal capacity show no adjustment of dietary protein and P supply to the operation size during the growing finishing period.

Net cost to handle manure was calculated by subtracting the manure collection, storage, and application costs from the fertilizer value of manure. The waste management cost per pig decreased as the animal capacity increased from 4,000 to 10,000, but only decreased little as the animal capacity increased from 10,000 to 16,000 in the simulation model. A similar trend was observed in the swine waste management model, upon which the waste management component of the simulation model was built. This indicates that economies of scale in term of manure management may occur only as the operation size increases from small to large. The competitiveness of swine feeding operation with greater feeder pig capacities may be partly based on lower manure management cost per animal space as the feeder pig capacity increased. As feed and waste management cost was directly incorporated in the system level swine feeding simulation model, the waste management cost in the integrated swine feeding problem was observed to be lower than that with the stepwise swine waste management model (Stoecker et al., 1998) in Table V-5.

The optimal ration for swine farms involved no microbial phytase addition when applicable land was adequate. Under the current price level of microbial phytase and the operation condition in the Panhandle, it is not economically competitive to reduce P excretion with substantially feed cost increase by including phytase addition in the optimal rations, when land area for manure application was adequate.

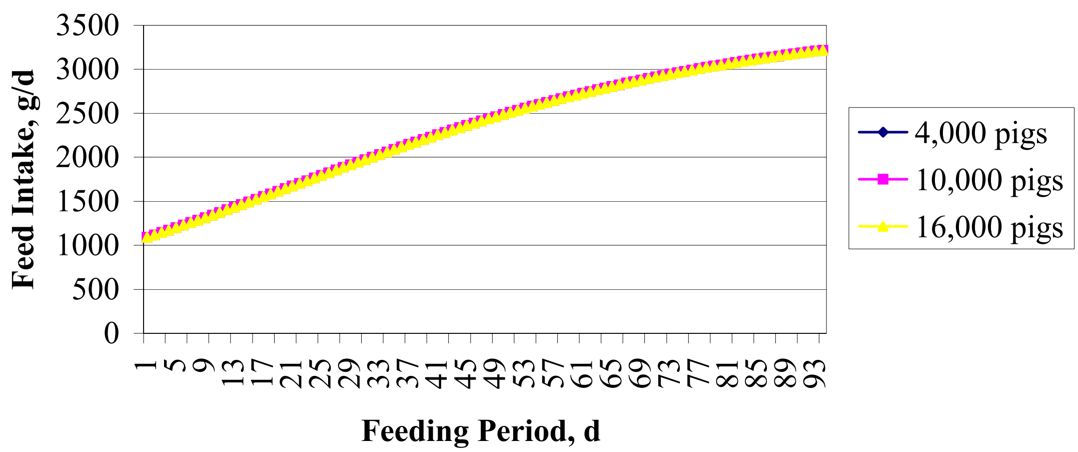

Figure V-25. The optimal feed intake in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

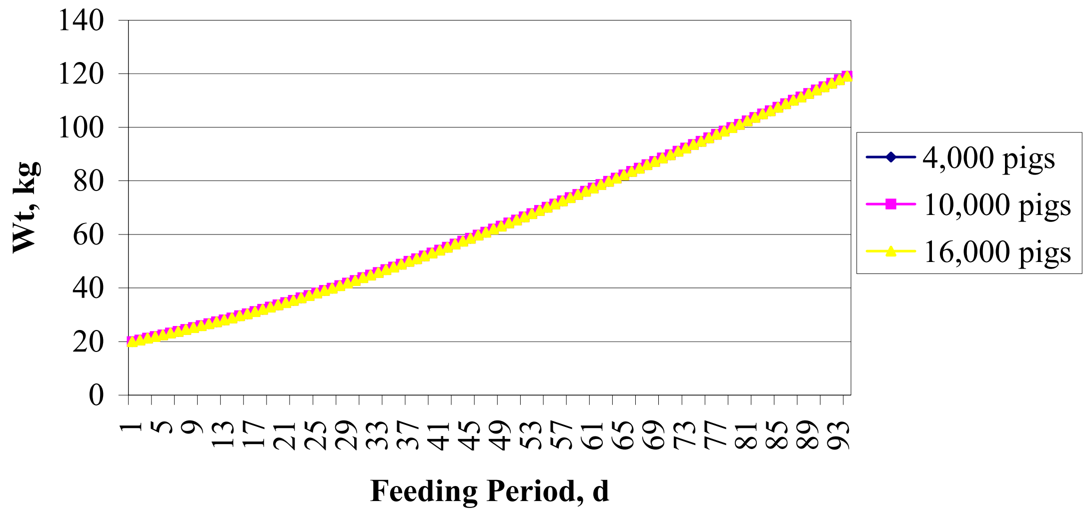

Figure V-26. The optimal final body weight in kg for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

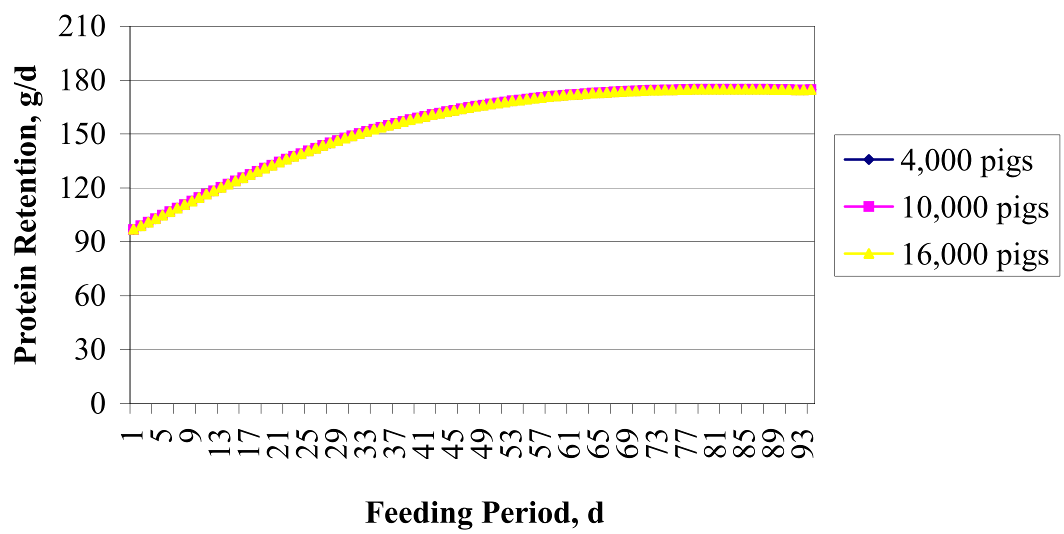

Figure V-27. The optimal whole body protein retention in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

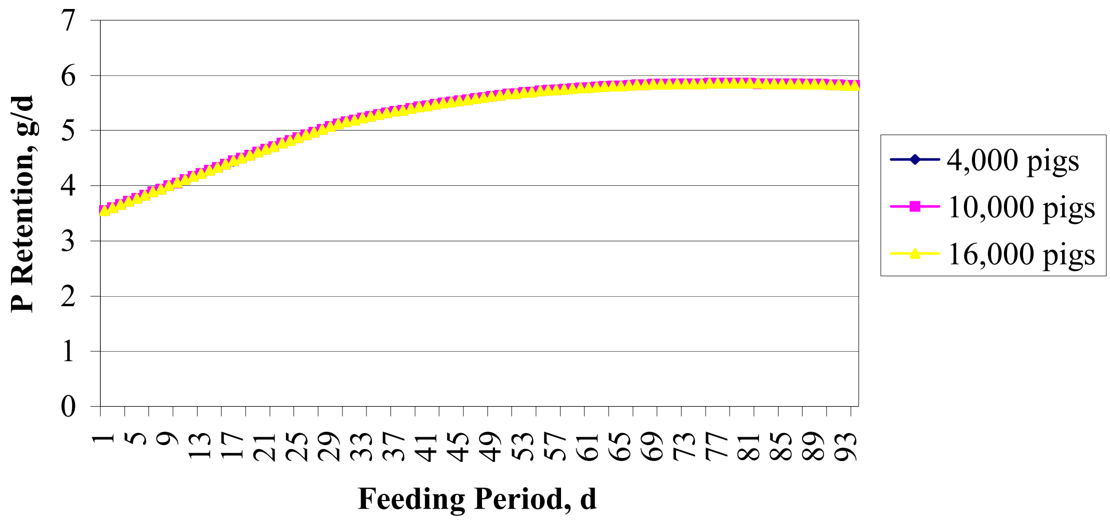

Figure V-28. The optimal P retention in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

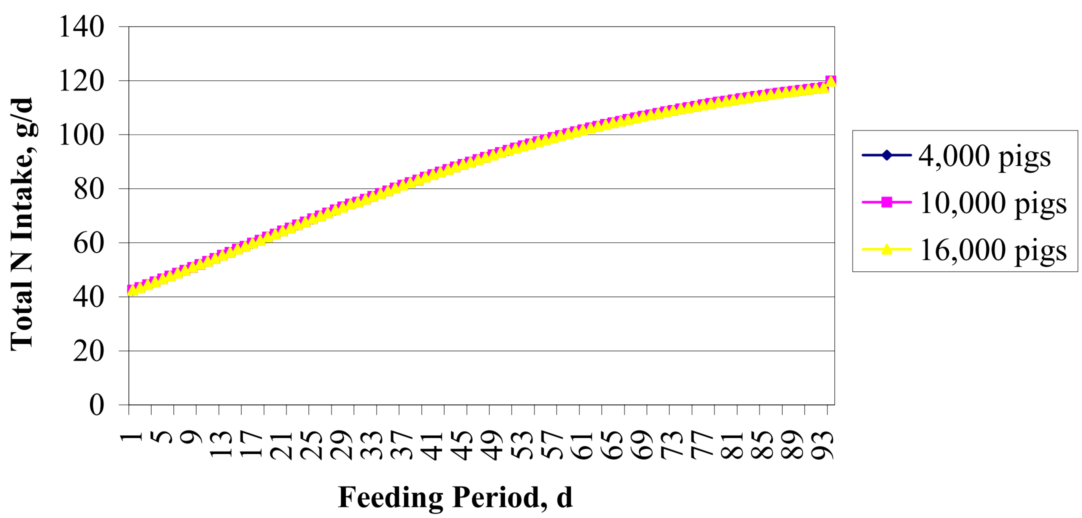

Figure V-29. The optimal N intake in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

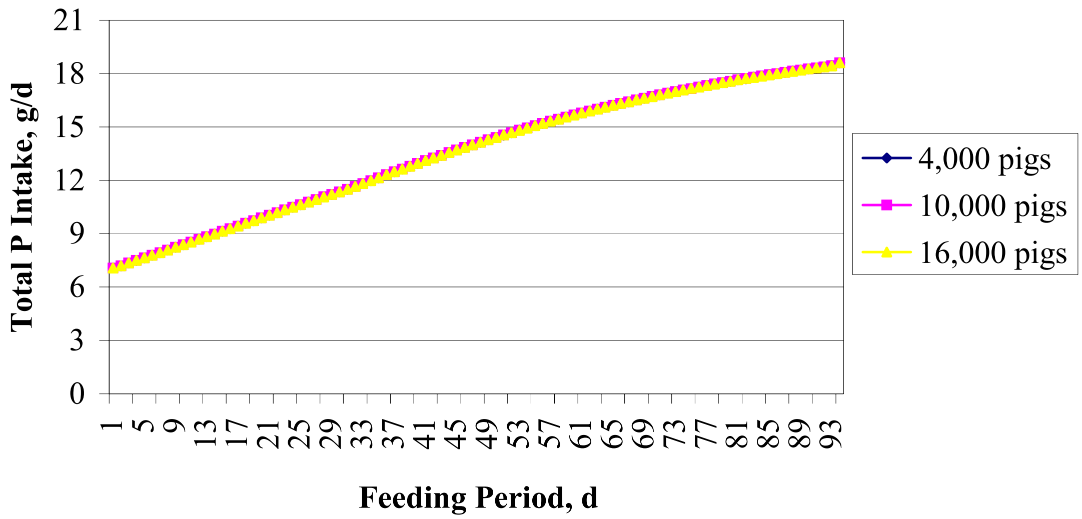

Figure V-30. The optimal P intake in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

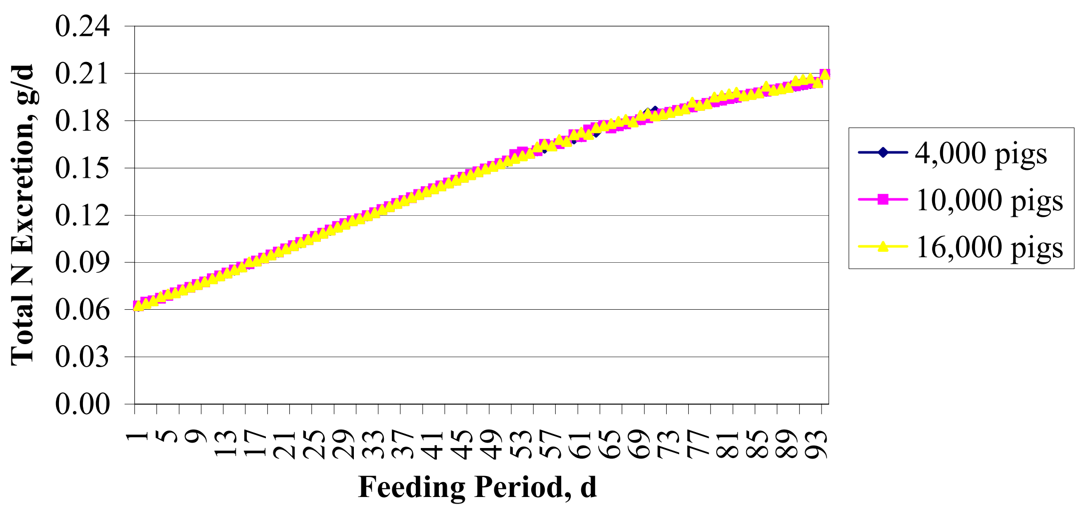

Figure V-31. The optimal N excretion in pound per day per pig for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

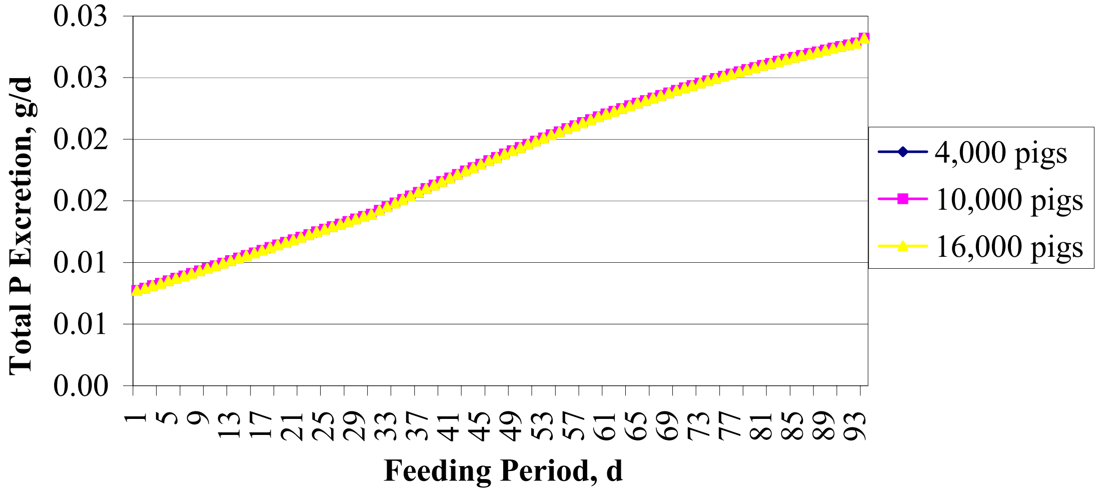

Figure V-32. The optimal P excretion in pound per day per pig for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

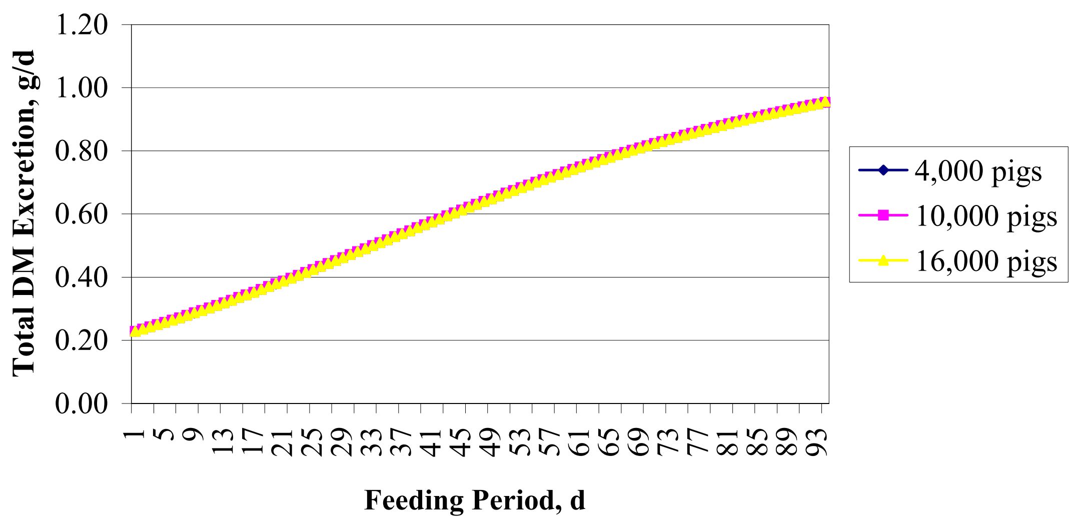

Figure V-33. The optimal DM excretion in pound per day per pig for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

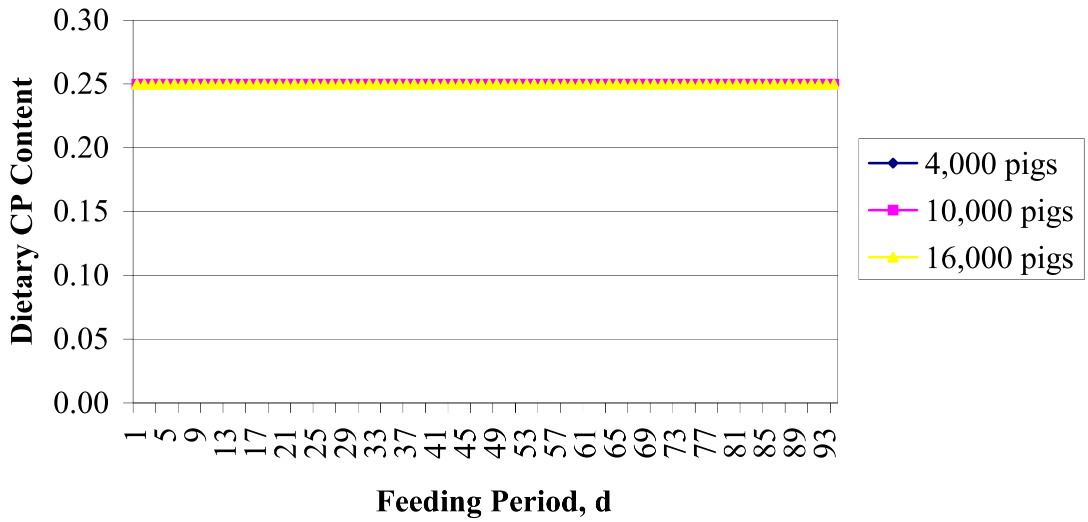

Figure V-34. The dietary CP content in the optimal diet for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

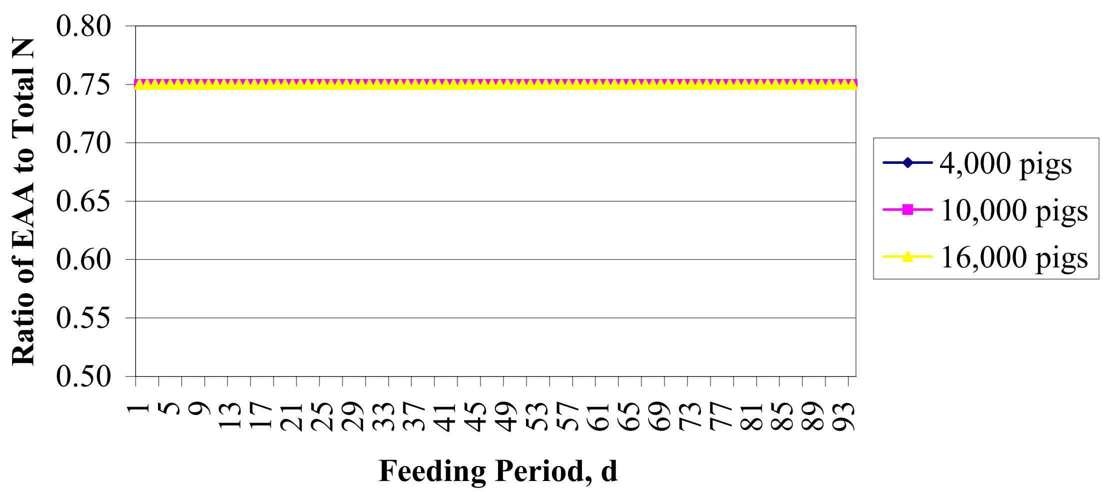

Figure V-35. The ratio of N from EAA to N from NEAA in the optimal diet for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

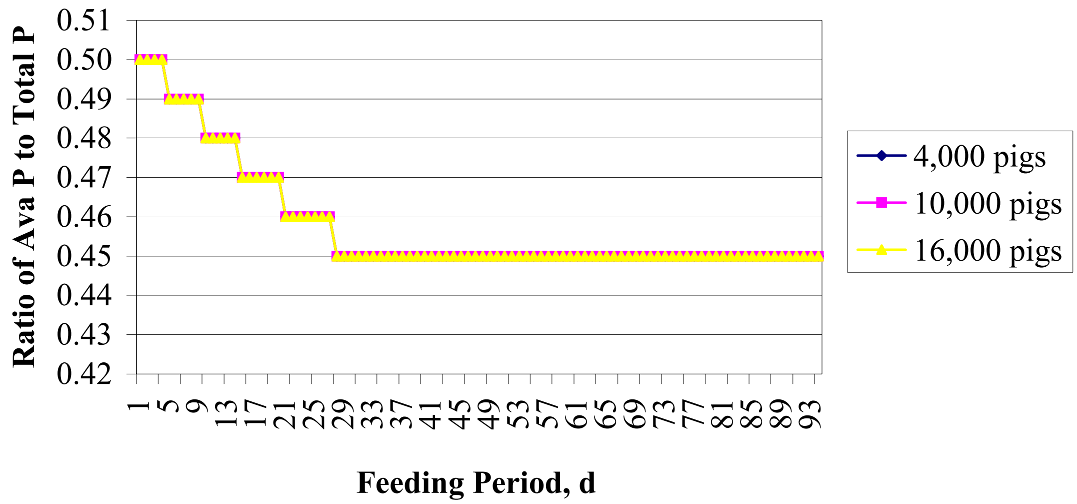

Figure V-36. The ratio of available P to total P in the optimal diets for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was adequate.

Effect of Applicable Acres on the Optimal Feeding under P Restriction

In the system-level profit maximization model, ingredient selection may serve as a means of preventing the N and P losses. When the area for land application of manure was not sufficient, preventive measures for reduction of N in manure became necessary, mainly through a better adjustment of nutrient supply in the feed, as N and P excretion are both costly and dexterous to the environment. An adjustment of animal growth to the overall profit maximization level at the different physiological stages is the first approach to reduce nutritional N and P losses. The second approach is to improve dietary amino acid balance or P availability and consequently reduce total CP and P content of the diet.

Carreira and Stoecker (2000) found that land available for waste application is a crucial factor in determining total waste management costs. Table V-5 shows that the cropland the swine feeding operations with 4,000, 10,000, and 16,000 pigs in the

Panhandle require to comply with the P restriction were 623, 1559, and 2465 acres, respectively. To investigate the effect of applicable cropland size on the optimal feeding strategy, that the available cropland was arbitrarily assumed to be the average farm size of the Panhandle, 834 acres. The optimal solutions obtained for three different animal capacities with applicable cropland of 834 acres were compared in Table V-6. Table V-6 shows that with 834 acres of cropland, the production level and waste management components and the related cost for the swine operations with 4,000 pig capacity were not changing since the required acres was still less than the amount of available cropland.

From the simulation model it was calculated that when pig capacity of the swine feeding operation increased from 4, 000 to 10,000, pig growth become slower when available cropland was 834 acres. Pig final body weight and the lean percent at slaughter were only slightly affected. Table V-6 shows that swine CAFO of greater sizes tended to grow swine to the similar final body weight in a longer feeding period under the restriction on P application. Similarly, the N, P, and DM excretion per pig produced decreased with increasing animal capacities as N, P, and DM intake and retention during the growing-finishing period was reduced when the size of swine operation increased from 4, 000 to 10,000 pigs. As available acre for land application was inadequate, the system becomes more sensitive to P excretion because hauling manure from the farm was costly. Figure V-42 and V-45 show that though the total P intake was lower when pig capacity increased from 4,000 to 10,000, the P excretion was reduced since it is economically competitive to include microbial phytase addition in the overall profit maximizing rations when application of P in manure had been restricted. Maximum microbial phytase addition of 1000 PU was frequently included in the optimal rations, as shown in the Appendix Table A5-12 of the detailed daily ration compositions.

When the size of swine feeding operation increased from 4,000 to 16,000 pigs, the economic impact of the manure disposal on swine production was even greater. With only 834 available acres to comply with the P-restriction, the cost associated with hauling the excess manure from farm was so great that microbial phytase was more widely used in the profit maximizing rations than in the swine feeding operations with 10,000 pig capacity, as indicated in the Appendix Table A5-12. Similar to the animal capacity of 10,000, when available acres for land application were inadequate, both the body weight and protein growth rates of pigs were slower in swine farms with 16,000 pigs. Because the cost to haul manure from the farm was relatively high in the manure handling system, the performance variables such as animal body weight and protein retention were subdued to help reduce P excretion (Figure V-38 and 5-39). With restricted available acres, farmer will produce small pigs of high quality (high lean percent).

Table V-6. The optimal solution of the system-level profit-maximizing problem for swine production under P restriction when applicable cropland was 834 acres.

Item\Capacity	4,000	10,000	16,000
Feeding Period, d	94	145	155
Profit, $/pig[a]	26.8	21.78	-7.5
Final Wt, kg	119.1	110.3	85.6
Lean Percent, %	49.2	50.3	51.0
Revenue, $/pig[a]	96.6	92.0	67.5
Feed Cost, $/pig	63.0	59.9	65.0
Waste Cost, $/pig 15 yrs[b]	194.7	265.8	258.4
CLG[c], $/ 15 yrs	87649	1.87×10^5	2.20×10^5
APC[d], $/ 15 yrs	101687	1.95×10^5	1.95×10^5
HOC[e], $/ 15 yrs	0	0	0
Acre			
Sorghum	623	834	834
Wheat	0	0	0
Lagoon Size, cuft	1.21×10^6	1.95×10^6	2.37×10^6
Manure App, cuft	1.21×10^6	1.95×10^6	2.37×10^6
Manure Haul, cuft	0	0	0
NCLG[f], lb/gal	0.033	0.022	0.019
PCLG[g], lb/gal	0.010	0.007	0.002
PU Addition	0	1000	1000

[a] The profit refers to the profit per pig (not including waste handling cost) in dollars for a single feeding period of 94 days.
[b] The waste cost refers to the waste management cost of 15 year period in dollars per pig.
[c] The total cost of anaerobic lagoon (LGC), which includes initial construction, land, and lifetime maintenance and repair cost.
[d] The total cost of application with a traveling gun for the continuing land application programs.
[e] The total cost of hauling excess manure off the farm.
[f] N content in lagoon liquid.
[g] P content in lagoon liquid.

Simulation results show that dietary P supply was also adjusted to enhance P retention and reduce P excretion during the growing finishing period when the size of swine feeding operation was increased to 16,000 pigs. The results obtained from empirical analysis confirmed our hypothesis that the applicable acres would affect the animal performance levels, dietary nutrient content and decision on enzyme usage. The manure management also exhibited economies of large scale in term of lagoon cost in the swine feeding operation with inadequate applicable land, as shown in the Table V-6. However, intensive swine feeding production was less competitive, when applicable cropland was not enough. Table V-6 shows that the profit from swine production was even negative, when animal capacity was 16,000 pigs. Decreasing profit per animal space as the feeder pig capacity increased when applicable cropland was not adequate may induce swine farms to reduce the production scale.

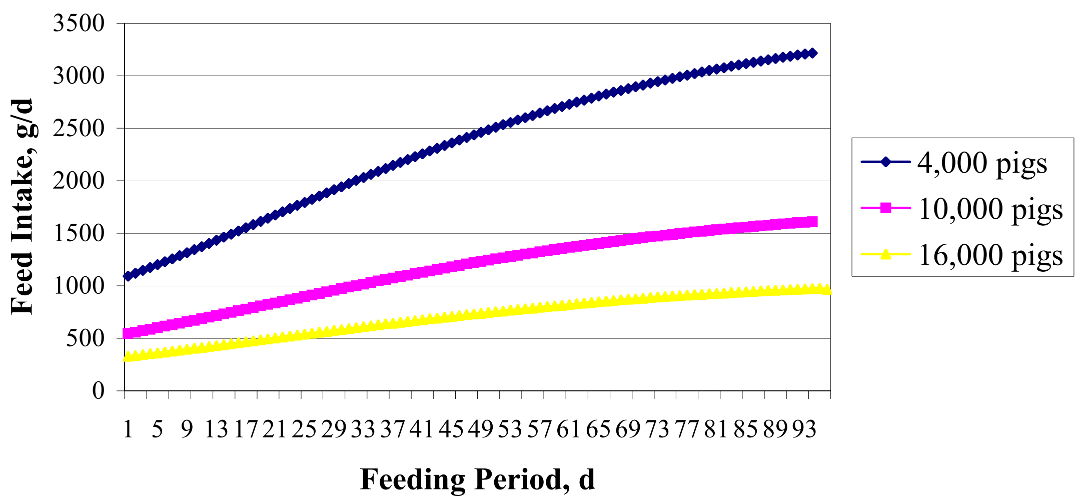

Figure V-37. The optimal feed intake in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

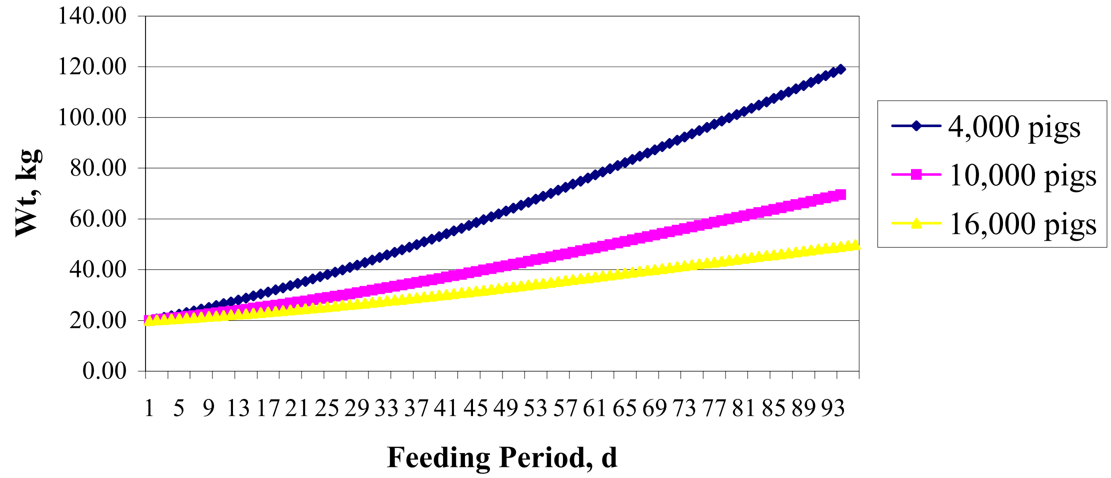

Figure V-38. The optimal final body weight in kg for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

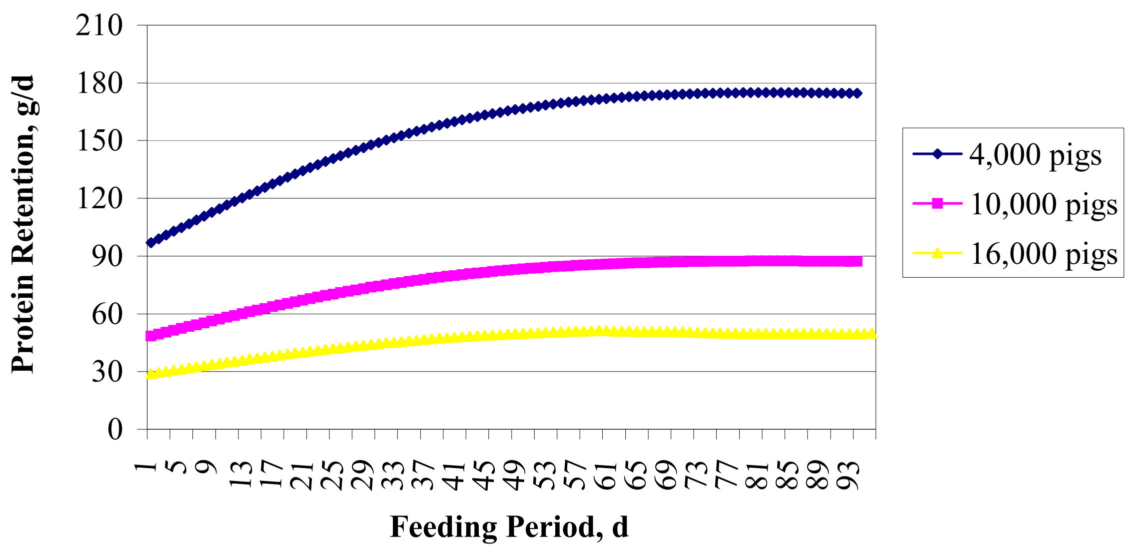

Figure V-39. The optimal whole body protein retention in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

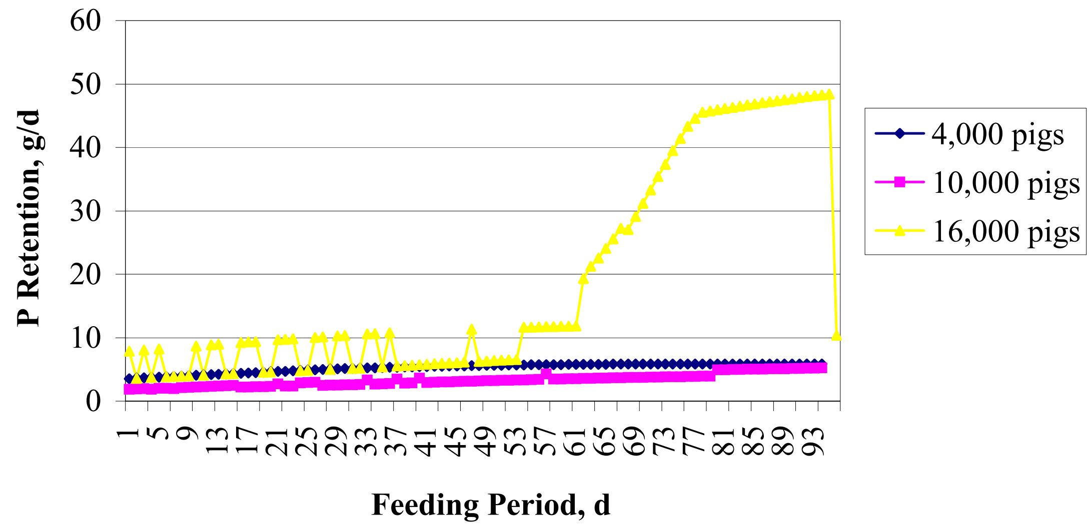

Figure V-40. The optimal P retention in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

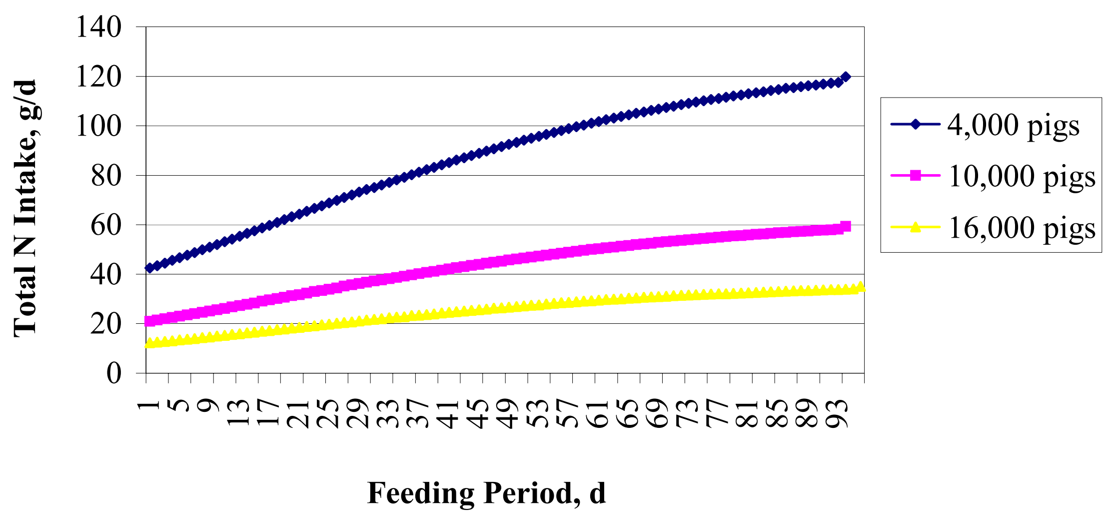

Figure V-41. The optimal N intake in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

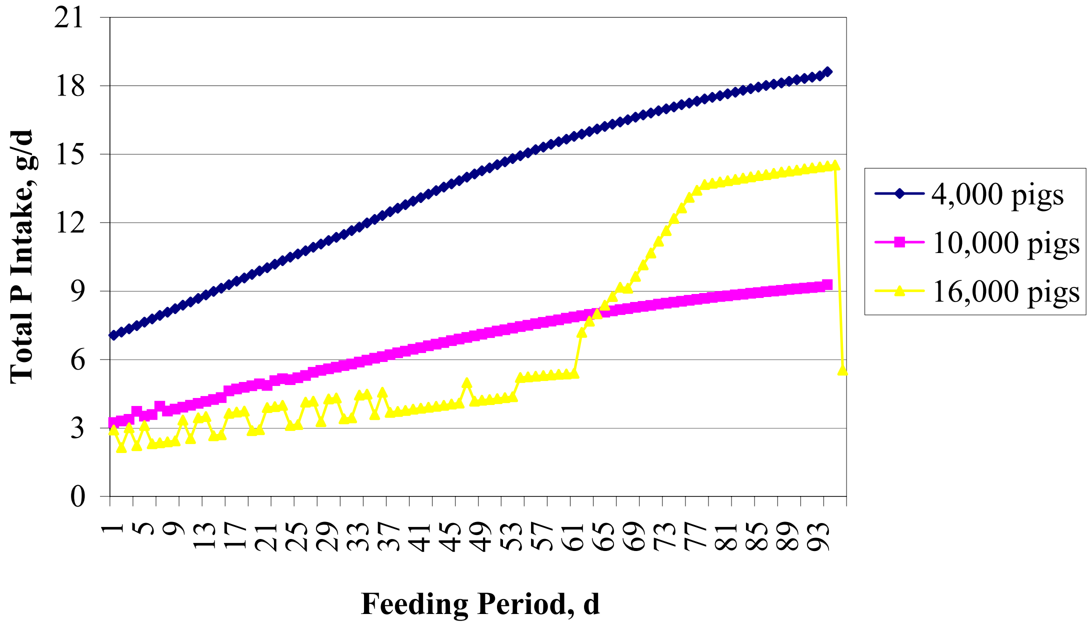

Figure V-42. The optimal P intake in grams per day for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

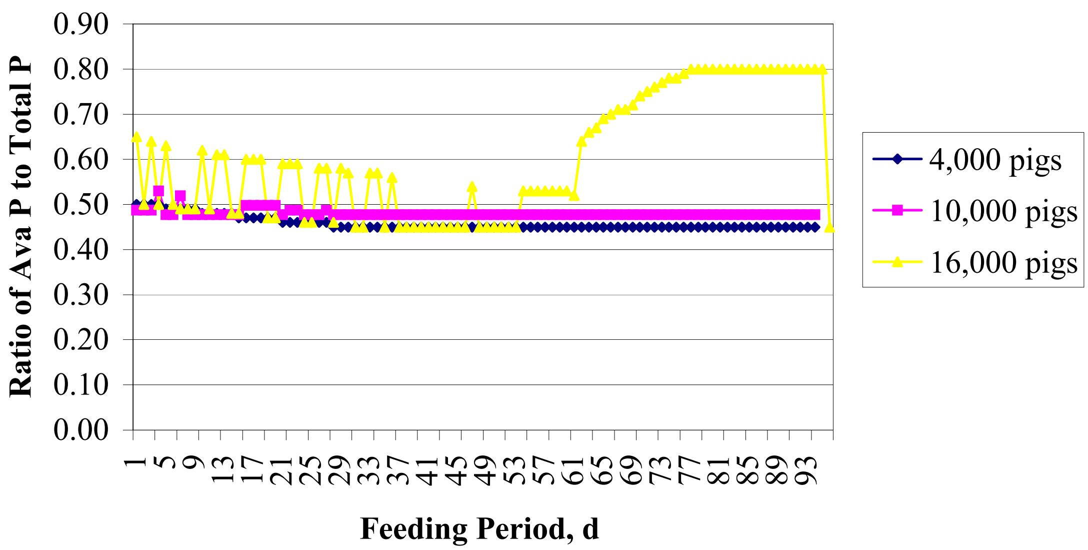

Figure V-43. The ratio of available P to total P in the optimal diets for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

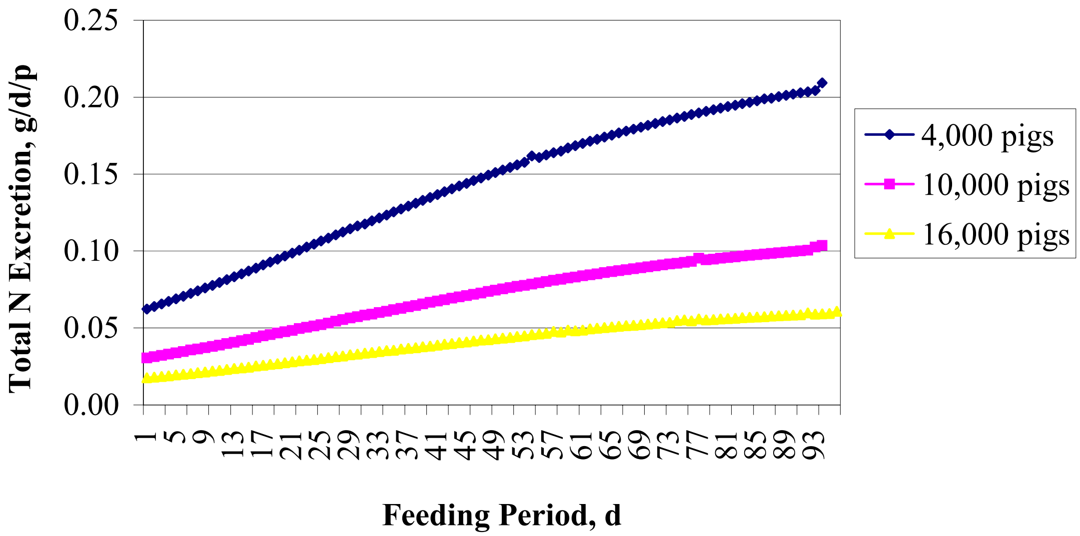

Figure V-44. The optimal N excretion in pound per day per pig for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

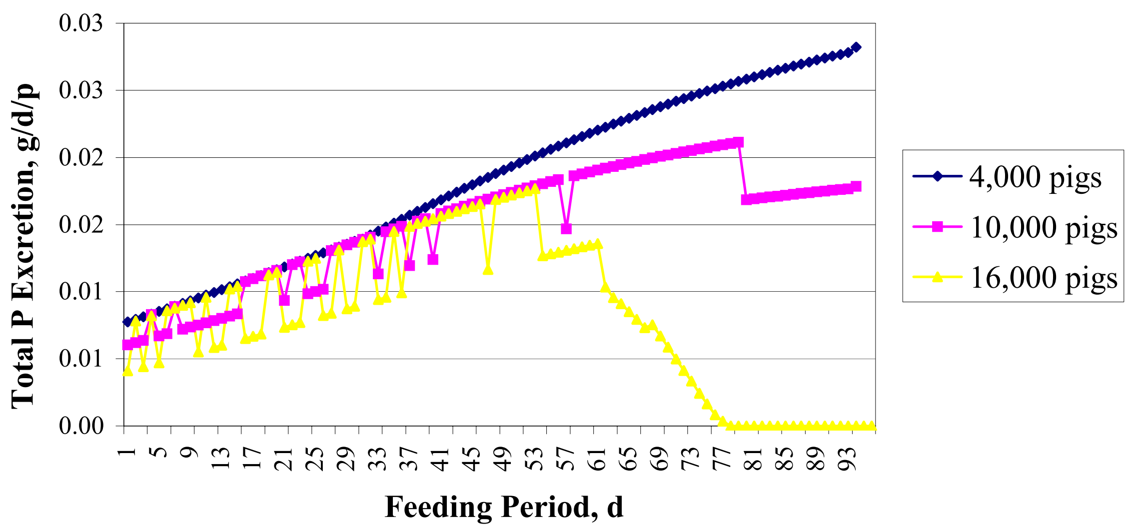

Figure V-45. The optimal P excretion in pound per day per pig for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

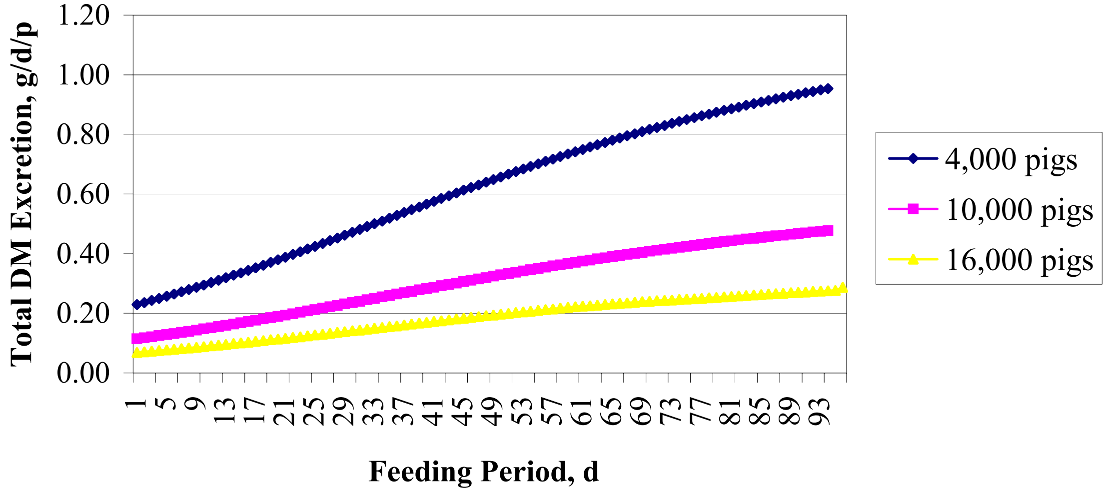

Figure V-46. The optimal DM excretion in pound per day per pig for the swine feeding operation with 4,000, 10,000, 16,000 pigs under a P restriction when applicable cropland was 834 acres.

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CHAPTER VI

CONCLUSION

Swine production has grown dramatically in recent years in Oklahoma. The total number of pigs in Oklahoma was increased from 215,000 head to 2,240,000 head within a decade (Oklahoma Agricultural Statistics Service). The industry's structure had also changed rapidly and substantially over the same period. In 1990s, the hog industry in Oklahoma began building large feeding operations in rural areas. The number of farms with an inventory of at least 5,000 pigs increased from 10 to 40 from 1993 to 2002. On the other hand, the number of farms with an inventory of less than 500 pigs decreased from 3,430 to 2,410 over the same period. The 40 largest farms produced 89 percent of all the pigs marketed in Oklahoma during 2003 in comparison with only 40 percent during 1993. In contrast, the market share of production from small farms (less than 500 head per year) dropped from 35 percent in 1993 to 2 percent in 2002. Large and intensive pig production operations have been associated with environmental problems and have aroused public concern about waste disposal. Management of manure in an environmentally sustainable manner is one of the critical issues facing the hog industry in Oklahoma.

The overall goal of this study was to reduce the burden of N and P excretion from swine production on the environment through seeking an environmental balance between N and P inputs in feed and outputs in pork and manure with economic analysis. The research methods employed in this study to implement remedial strategies that minimize P loss from swine production involved interdisciplinary research such as animal science, soil science, agronomy, and hydrology.

In Chapter II, the simulation model based on the *Nutrient requirements of Swine* (NRC, 1998) was built. In the model, genotype, and temperature were held constant. In the NRC simulation model, the protein requirements are expressed in terms of total body weight. The lean meat content in carcasses is used as a measure of hog quality by the industry. The carcass fat free lean meat rate is derived from daily protein accretion. The NRC simulation model can then be used to determine the optimal final body weight and carcass composition in the profit maximization problem. The essential amino acids and P requirements given specific growth rates were estimated by the biological functions that describe the relationship between growth rate and nutrient requirement in the NRC model.

Given that feed accounts for 55 to 70 percent of the total cost of pork production (Swine Nutrition Fact Sheet-3500, Oklahoma Cooperative Extension Service), the profitability of hog feeding operations is concerned with pig growth performance as well as the cost structure, which is directly dependent on the dietary regime. In Chapter III, a general profit maximization model in which optimal rations were formulated from diverse feed ingredients with a range of protein and phosphorus contents was built. The effect of swine diet formulation on returns and cost from a representative feeder pig-to-finishing operation in Oklahoma was determined. With a manure handling system that combined fully slated floor, pull plug, anaerobic lagoon, and effluent application with a traveling gun, the related waste management components and cost were also estimated by the Decision Support System (Stoecker et al., 1998).

In Chapter IV, the NRC simulation model was validated against results from a series of low crude protein and phosphorus feeding trials conducted at Oklahoma State University (Carter et al., 1999; 2000; 2001; 2003). The simulation values of daily DE intake, as well as protein and P retention were found to be significantly different than the experimental values. The difference between the simulated and the experimental values of important growth variables was attributed to two causes. First, growth measurements taken from cages of pigs under experimental growing conditions are not expected the same as the initial NRC simulation model that was derived from commercial production. To address this issue, the DE intake as well as protein and P retention equations in the initial NRC simulation model were first re-estimated with the experimental data on the corn-SBM diet. Second, the statistical analysis suggested that growth variables might also be affected by dietary treatments. The growth variables of the simulation model were re-estimated as well by including adjustment terms of dietary nutrient content. The extent to which animal's growth was influenced by diets, formulated with low crude protein, low phosphorus but higher quality ingredients while satisfying the same bio-available nutrient requirements was measured and discussed. The results show the adjustment terms improved the prediction ability of swine growth and nutrient requirement model.

In the Chapter V, the modified NRC swine growth and nutrient requirement model described in Chapter VI as well as N and P contents in the feedstuffs published by the NRC (1998) and other institutes was used as basis to estimate nitrogen and phosphorus excretion from alternative diets. The methods used to calculate the amount of

N, P and DM excretion with the growth and nutrient requirement model were presented, followed by empirical analysis on the prediction of N, P and DM intake and excretion. As more strict legislation is passed by the federal government and state governments as well to regulate animal manure disposal, the introduction of environmental objectives in the ration formulation process is necessary to improve the competitiveness of swine production. This can be done by taking both ingredient cost and manure management cost into account. In Chapter V, a profit-maximizing problem that included waste management cost components was constructed using a well-established mathematical programming model. The optimal growth trajectory and body protein retention as well as dietary regimes were determined under nitrogen and phosphorus limitations. System level swine production was found to be more efficient in term of waste management than the stepwise swine production that was estimated in Chapter III. With adequate cropland for manure application, the large swine feeding operation was more competitive than the small swine feeding operation. This was partly because the waste management cost per pig decreased as the animal capacity increased. When cropland for manure application was insufficient, the large swine operation became less competitive, as hauling the excess manure was costly. In this situation, small swine feeding operation may have higher overall profit than the large swine CAFO because of their lower manure handling cost.

The integrated feeding manure management system analyzed in this study can provide the basis to increase N and P use-efficiency in swine production systems. The analysis explored the possibility to implement management practices that minimize soil P buildup in excess of crop requirements and reduce N and P loss in agricultural runoff via economic incentives.

In summary, management systems that attempt to balance N and P inputs and outputs at farms could be more efficient than pollution control and management at watershed scales. It is necessary to develop extension projects that consider all these factors to educate farmers, the livestock industry as to what is actually involved in ensuring environment friendly swine production. Hopefully, this study will help minimize the environmental impact caused by swine production, and overcome the common misconception that swine manure is costly to manage, or variable to control.

APPENDICES

APPENDIX A

The GAMS Program Used for the Simulation Model

```
$TITLE Profit Maximization Growth for Pigs
$OFFUPPER OFFSYMXREF OFFSYMLIST OFFUELLIST OFFUELXREF
OPTION LIMROW=0, LIMCOL=0
OPTION NLP=MINOS
OPTION iterlim=100000
OPTION reslim=100000;


SETS
J feeds
/L-tryptophan, Corn, DL-methionine, SBM, L-lysine, L-threonine, DicalciumP,
LimstonG, Casein, Cornstarch, SPI/

I nutrient constraints
/Aginine, Histidine, Lysine, Tryptophan, Phenylalanine, Phenylalanine+Tyrosine,
Methionine,
Methionine+Cystine, Threonine, Leucine, Isoleucine, Valine/

T feeding days
/1*94/

pl nutrient removing plants
/DL-sorghum, DL-wheat/        ;


PARAMETER AAm(I)
/
Aginine                  -2
Histidine                 0.32
Lysine                    1
Tryptophan                0.26
Phenylalanine             0.50
Phenylalanine+Tyrosine    1.21
Methionine                0.28
Methionine+Cystine        1.23
Threonine                 1.51
Leucine                   0.70
Isoleucine                0.75
Valine                    0.67 /;

PARAMETER AAp(I)
/
Aginine                   0.48
Histidine                 0.32
Lysine                    1
Tryptophan                0.18
```

Phenylalanine 0.60
Phenylalanine+Tyrosine 0.93
Methionine 0.27
Methionine+Cystine 0.55
Threonine 0.60
Leucine 1.02
Isoleucine 0.54
Valine 0.68 /;

PARAMETER EAANC(I)
/

Aginine	0.32
Histidine	0.27
Lysine	0.19
Tryptophan	0.14
Phenylalanine	0.09
Phenylalanine+Tyrosine	0.08
Methionine	0.09
Methionine+Cystine	0.10
Threonine	0.12
Leucine	0.11
Isoleucine	0.11
Valine	0.12 /;

TABLE A(I,J) the amino acid composition of feeds(g)

	L-tryptophan	Corn	DL-methionine	SBM
Aginine	0	0.0037	0	0.0323
Histidine	0	0.0023	0	0.0117
Lysine	0	0.0026	0	0.0283
Tryptophan	0.98	0.0006	0	0.0061
Phenylalanine	0	0.0039	0	0.0218
Phenylalanine+Tyrosine	0	0.0064	0	0.0387
Methionine	0	0.0017	0.99	0.0061
Methionine+Cystine	0	0.0036	0.99	0.0131
Threonine	0	0.0029	0	0.0173
Leucine	0	0.0099	0	0.0342
Isoleucine	0	0.0028	0	0.0199
Valine	0	0.0039	0	0.0206

\+

	L-lysine	L-threonine	DicalciumP
Aginine	0	0	0
Histidine	0	0	0
Lysine	0.78	0	0
Tryptophan	0	0	0
Phenylalanine	0	0	0

Phenylalanine+Tyrosine	0	0	0	
Methionine	0	0	0	
Methionine+Cystine	0	0	0	
Threonine	0	0.99	0	
Leucine	0	0	0	
Isoleucine	0	0	0	
Valine	0	0	0	
+	LimstonG	Casein	Cornstarch	SPI
Aginine	0	0.0326	0	0.0687
Histidine	0	0.0282	0	0.0225
Lysine	0	0.0735	0	0.0526
Tryptophan	0	0.0114	0	0.0108
Phenylalanine	0	0.0479	0	0.0434
Phenylalanine+Tyrosine	0	0.0478	0	0.0372
Methionine	0	0.0270	0	0.0101
Methionine+Cystine	0	0.0156	0	0.011
Threonine	0	0.0398	0	0.0317
Leucine	0	0.0879	0	0.0664
Isoleucine	0	0.0466	0	0.0425
Valine	0	0.0610	0	0.0421 ;

TABLE B(I,J) True Ileal Digestibility of Amino Acids in feeds

	L-tryptophan	Corn	DL-methionine	SBM
Aginine	0	0.89	0	0.93
Histidine	0	0.87	0	0.90
Lysine	0	0.78	0	0.89
Tryptophan	1	0.84	0	0.87
Phenylalanine	0	0.90	0	0.88
Phenylalanine+Tyrosine	0	0.90	0	0.89
Methionine	0	0.90	1	0.91
Methionine+Cystine	0	0.88	1	0.88
Threonine	0	0.82	0	0.85
Leucine	0	0.92	0	0.88
Isoleucine	0	0.87	0	0.88
Valine	0	0.87	0	0.86

+

	L-lysine	L-threonine	DicalciumP
Aginine	0	0	0
Histidine	0	0	0
Lysine	0	0	0
Tryptophan	0	0	0
Phenylalanine	0	0	0
Phenylalanine+Tyrosine	0	0	0

```
Methionine                0          0              0
Methionine+Cystine        0          0              0
Threonine                 0          0.99           0
Leucine                   0          0              0
Isoleucine                0          0              0
Valine                    0          0              0

+                      LimstonG    Casein     Cornstarch    SPI
Aginine                   0          1            0          1
Histidine                 0          1            0          1
Lysine                    0          1            0          1
Tryptophan                0          1            0          1
Phenylalanine             0          1            0          1
Phenylalanine+Tyrosine    0          1            0          1
Methionine                0          1            0          1
Methionine+Cystine        0          1            0          1
Threonine                 0          1            0          1
Leucine                   0          1            0          1
Isoleucine                0          1            0          1
Valine                    0          1            0          1   ;


PARAMETER E(J) the digestible energy content of feeds (Kcal per g)
/ L-tryptophan       0
  Corn               3.525
  DL-methionine      0
  SBM                3.490
  L-lysine           0
  L-threonine        0
  DicalciumP         0
  LimstonG           0
  Casein             4.135
  Cornstarch         4.000
  SPI                4.15      /;

PARAMETER Ng(J) the nitrogen content of feeds
/ L-tryptophan       0.14
  Corn               0.01328
  DL-methionine      0.09
  SBM                0.076
  L-lysine           0.19
  L-threonine        0.12
  DicalciumP         0
  LimstonG           0
  Casein             0.1492
```

```
  Cornstarch           0.00048
  SPI                  0.13728  /;

PARAMETER H(J) the total phosphorus contents of feeds
/ L-tryptophan         0
  Corn                 0.0028
  DL-methionine        0
  SBM                  0.0065
  L-lysine             0
  L-threonine          0
  DicalciumP           0.1850
  LimstonG             0.0001
  Casein               0.0082
  Cornstarch           0.0003
  SPI                  0.0065    /;

PARAMETER O(J) the bioavailability of phosphorus in feeds
/ L-tryptophan         0
  Corn                 0.14
  DL-methionine        0
  SBM                  0.31
  L-lysine             0
  L-threonine          0
  DicalciumP           1
  LimstonG             1
  Casein               1
  Cornstarch           1
  SPI                  1           /;

PARAMETER CA(J) the calcium contents of feeds
/ L-tryptophan         0
  Corn                 0.0003
  DL-methionine        0
  SBM                  0.0032
  L-lysine             0
  L-threonine          0
  DicalciumP           0.2200
  LimstonG             0.3584
  Casein               0.0061
  Cornstarch           0
  SPI                  0.0015        /;

PARAMETER NDF(J) the NDF contents of feeds
/ L-tryptophan         0
  Corn                 0.096
  DL-methionine        0
```

```
  SBM                 0.089
  L-lysine            0
  L-threonine         0
  DicalciumP          0
  LimstonG            0
  Casein              0
  Cornstarch          0
  SPI                 0        /;

PARAMETER DM(J) the DM contents of feeds
/ L-tryptophan        0
  Corn                0.89
  DL-methionine       0
  SBM                 0.90
  L-lysine            0
  L-threonine         0
  DicalciumP          0
  LimstonG            0
  Casein              0.91
  Cornstarch          0.99
  SPI                 0.92     /;


PARAMETER P(J) the prices of feeds (dollar per g)
/ L-tryptophan        0.034000
  Corn                0.00009348
  DL-methionine       0.002690
  SBM                 0.00020013
  L-lysine            0.006040
  L-threonine         0.003250
  DicalciumP          0.00039648
  LimstonG            0.00002756
  Casein              0.00458
  Cornstarch          0.000728
  SPI                 0.007645     /;

PARAMETER Cg(J) the percentage changes in the prices of feeds
/ L-tryptophan        1
  Corn                1
  DL-methionine       1
  SBM                 1
  L-lysine            1
  L-threonine         1
  DicalciumP          1
  LimstonG            1
  Casein              1
```

```
  Cornstarch          1
  SPI                 1   /;

Parameter g(pl) the prices of nutrient removing plants (dollar per bushel)
/DL-sorghum        3.66
 DL-wheat          3.07  /;

Parameter X(pl) the yield of nutrient removing plants (bushel per acre)
/DL-sorghum        35
 DL-wheat          28  /;

Parameter NTO(pl) the amount of N removed by plants (lb per bushel)
/DL-sorghum        32.7
 DL-wheat          34.9  /;


Parameter PTO(pl) the amount of P removed by plants (lb per acre)
/DL-sorghum        18.7
 DL-wheat          34.5  /;


SCALAR Pn the price of fertilizer N (dollar per lb)
/ 0.18 /;


SCALAR Pp the price of fertilizer P (dollar per lb)
/ 0.19 /;



SCALAR Pb the base price with 51 percent lean (dollar per kg)
/ 0.988/ ;



SCALAR d the daily interest rate
/ 0.000274 / ;


SCALAR m Temperature ('C)
/ 20 / ;


SCALAR gy genotype
/ 350 / ;
```

SCALAR Cf the costs of feeder pig
/ 36.85 / ;

SCALAR nb pig capacity
/ 4000 / ;

SCALAR dmv daily manure volume (cuft per day)
/ 3927 / ;

SCALAR ihc inhouse cost (dollar)
/ 978849 / ;

SCALAR DT the change in the waste management cost
/ 1 / ;

VARIABLES

NPV	net present value of profits (dollar)
Y(T,J)	feed levels (g)
DEI(T)	digestible energy intake (kcal per day)
DET(T)	digestible energy content
TNIT(T)	total N intake (g per d)
TPIT(T)	total P intake (g per d)
NExc(T)	daily N excretion (lb per d)
PExc(T)	daily P excretion (lb per d)
DMExc(T)	daily DM excretion (lb per d)
DBWG(T)	daily body weight gain (g per day)
BW(T)	body weight (kg)
LBW(T)	natural logarithm of body weight (kg)
WBPG(T)	whole body protein gain (g per day)
RAEN(T)	ratio of EAAN to NEAAN
EAANIT(T)	N intake from EAA in the diet (g per day)
NEAANIT(T)	N intake from NEAA in the diet (g per day)
TNCont(T)	total N content in the diet
RANI(T)	the ratio of EAAN to total dietary N
PHR(T)	daily P retention (g per day)
Pe(T)	daily phytase intake level
CPTE(T)	phytase cost (dollar per day)
RAPI(T)	ratio of available P to total P
MWBPG	mean whole body protein gain (g per day)
FFLG(T)	carcass fat free lean gain (g per day)

IFFL	initial carcass fat free lean weight(g)
FTG(T)	fat tissue gain (g per day)
FSY(T)	fat synthesized (g per day)
PTG(T)	protein tissue gain (g per day)
ARM(T,I)	essential amino acids requirements for maintaince (g per day)
ARP(T,I)	essential amino acids requirements for protein gain (g per day)
EAAR(T,I)	total EAA requirement (g per day)
LNCR	net crop production revenue
LD(pl)	the acres planting pl
MA(pl)	the volume manure applied to crop pl (gallon)
MS	the volume excess manure hauled off from the farm (gallon)
CMA	manure apllication cost
SLG	lagoon size
CLG	lagoon cost
CHO	haul off cost
NCLG	N content in lagoon liquid
PCLG	P content in lagoon liquid
LGP	life time revenue
LTC	life time total cost
LVC	life time feed cost
CAR(T)	calcium requirements (g per day)
FI(T)	feed intake (g per day)
LP	lean percent
FBW	final body weight
U1	discount rate on LP
U2	discount rate on FBW

POSITIVE VARIABLE Y, DEI, DET, TNIT, TPIT, NExc, PExc, DMExc, DBWG, LBW, BW, WBPG, RAEN, EAANIT, NEAANIT, TNCont, RANI, PHR, CAR, RAPI, FFLG, FTG, FSY, PTG, ARM, ARP, EAAR, L, MA, MS, CMA, SLG, CLG, CHO, NCLG, PCLG, LGP, LTC, LVC, FI, LP, FBW, U1, U2;

EQUATIONS

OBJ	profits to be maximized
IBW	initial body weight
BWA(T)	body weight accumulation on day T
MT(T)	monotonic transformation
DBWA(T)	daily body weight gains
NUTRI(T,I)	nutrient requirements
RSEU(T)	maximum energy intakes
DETE(T)	dietary DE content equation
RSEL(T)	minimum energy intakes
WBPGEN(T)	whole body protein gain based on energy intake
RAENE(T)	ratio of EAAN to NEAAN equation
EAANE(T)	N intake from EAA equation
NEAANE(T)	N intake from NEAA equation

```
TNCE(T)        total dietary N content equation
RANIE(T)       the ratio of EAAN to total dietary N equation
FEN(T)         fat tissue gain based on energy intake
FEN1(T)        fat synthesis based on energy intake
CWF(T)         conversion of whole body protein to carcass FFL
CPT(T)         conversion of whole body protein to protein tissue
IFFLE          initial carcass fat free lean weight estimation
IRM(T,I)       ideal ratios of amino acids required for maintenance
IRP(T,I)       ideal ratios of amino acids required for protein gain
EAARE(T,I)     EAA requirement equation
ESI(T)         energy balance identity
BPRI(T)        bioavailable phosphorus requirement identity
RAPIE(T)       ratio of available P to total P equation
BPI(T)         bioavailable phosphorus balance identity
PTECE(T)       cost of phytase equation
TPI(T)         total P intake equation
TNI(T)         total N intake equation
NExcE(T)       daily N excretion equation
PExcE(T)       daily P excretion equation
DMExcE(T)      daily DM excretion equation
SLGE           lagoon size equation
CLGE           lagoon cost equation
CMAE           manure application cost equation
CHOE           haul off cost equation
CARI(T)        calcium requirement identity
CAI(T)         calcium balance identity
LNCRE          life time net crop revenue equation
NCLGE          N content in lagoon liquid equation
PCLGE          P content in lagoon liquid equation
NPCE(pl)       P application constraint
MUTE           total manure utilization identity
LACE           total available land constraint equation
LGPI           life time revenue equation
LTCI           life time total cost equation
LFCI           life time feed cost equation
FII(T)         feed intake equation
FBWI           final body weight equation
LPI            lean percent equation
PDI            discount equation for LP
WDI            discount equation for FBW  ;


IBW..       BW("1")=E=20;

ESI(T)..    SUM(J, E(J)*Y(T,J))=G=DEI(T);
```

```
FII(T)..     FI(T)=E=SUM(J, Y(T,J));

RSEL(T)..     DEI(T)=G=110*(BW(T)**0.75);

TNI(T)..     TNIT(T)=E=SUM(J, Ng(J)*Y(T,J));

TPI(T)..     TPIT(T)=E=SUM(J, H(J)*Y(T,J));

TNIT.LO(T)=0.0001;

RANI.LO(T)=0.3;

RANI.UP(T)=0.7;

RANIE(T)..     RANI(T)=E=EAANIT(T)/TNIT(T);

FI.LO(T)=0.0001;

DET.LO(T)=3;

DET.UP(T)=4;

DETE(T)..     DET(T)=E=SUM(J, E(J)*Y(T,J))/FI(T);

RSEU(T)..     EXP(-
17.8017*RANI(T)+11.476*(RANI(T)**2)+1.83*RANI(T)*DET(T)+2.22*DET(
T)-0.41*(DET(T)**2))*13162*(1-EXP(-0.0176*BW(T)))=G=DEI(T);

TNCont.Lo(T)=0.01;

TNCont.UP(T)=0.05;

RAEN.Lo(T)=0.4;

RAEN.UP(T)=2.5;

TNCE(T)..     TNCont(T)=E=TNIT(T)/FI(T);

EAANE(T)..     EAANIT(T)=E=sum(I, EAANC(I)*SUM(J,
A(I,J)*B(I,J)*Y(T,J)));

NEAANE(T)..     NEAANIT(T)=E=TNIT(T)-EAANIT(T);

NEAANIT.LO(T)=0.0001;

RAENE(T)..     RAEN(T)=E=EAANIT(T)/NEAANIT(T);
```

```
WBPGEN(T)..    WBPG(T)=L=(1-EXP(1.5474*RAEN(T)-70.6212*TNCont(T)-
88.5842*RAEN(T)*TNCont(T)))*(16.25+17.5*EXP(-
0.0192*BW(T)))*((gy/2.55)/125)*(1+0.015*(20-m))*(DEI(T)-
0.55*110*(BW(T)**0.75))/1000;

FEN1(T)..      FSY(T)=E=((0.96*DEI(T)-10.6*WBPG(T)-
106*(BW(T)**0.75))/12.5);

FEN(T)..       FTG(T)=E=((0.96*DEI(T)-10.6*WBPG(T)-
106*(BW(T)**0.75))/12.5)/0.9;

CPT(T)..       PTG(T)=E=WBPG(T)/0.23;

DBWA(T)..      DBWG(T)=E=(PTG(T)+FTG(T))/0.94;

BWA(T+1)..     BW(T+1)=E=BW(T)+(DBWG(T)/1000);

IRM(T,I)..     ARM(T,I)=G=0.036*(BW(T)**0.75)*AAm(I);

IRP(T,I)..     ARP(T,I)=G=0.12*WBPG(T)*AAp(I);

EAARE(T,I)..   EAAR(T,I)=E=ARM(T,I)+ARP(T,I);

Nutri(T,I)..   SUM(J, A(I,J)*B(I,J)*Y(T,J))=G=EAAR(T,I);

BW.LO(T)=20;

MT(T)..        LBW(T)=E=log(BW(T));

TPIT.LO(T)=0.0001;

RAPI.LO(T)=0.45;

RAPI.UP(T)=1;

RAPIE(T)..     RAPI(T)=E=SUM(J, O(J)*H(J)*Y(T,J))/TPIT(T);

BPRI(T)..      PHR(T)=L=EXP(4.7-21.8*RAPI(T)+34.4*(RAPI(T)**2)-
18.2*(RAPI(T)**3))*(EXP(-0.0557-
0.416*LBW(T)+0.005*(LBW(T)**2))/100)*DEI(T)/3.4;

Pe.LO(T)=0;

Pe.UP(T)=1000;
```

```
BPI(T)..      SUM(J, (1+0.000253*Pe(T))*O(J)*H(J)*Y(T,J))=G=EXP(4.7-
21.8*RAPI(T)+34.4*(RAPI(T)**2)-18.2*(RAPI(T)**3))*(EXP(-0.0557-
0.416*LBW(T)+0.005*(LBW(T)**2))/100)*DEI(T)/3.4;


PTECE(T)..     CPTE(T)=E=1.054*SUM(J,
0.000253*Pe(T)*O(J)*H(J)*Y(T,J))/453.5924;

CARI(T)..      CAR(T)=E=(EXP(-0.0658-0.1023*LBW(T)-
0.0185*(LBW(T)**2))/100)*(1250+188*BW(T)-
1.4*(BW(T)**2)+0.0044*(BW(T)**3))/3.4;

CAI(T)..       SUM(J, CA(J)*Y(T,J))=G=CAR(T);

NExcE(T)..     NExc(T)=E=(365/(card(T)+5))*(nb/453.5924)*(TNIT(T)-SUM(I,
EAANC(I)*EAAR(T,I))-(WBPG(T)-SUM(I, EAAR(T,I)))/6.25);

PExcE(T)..     PExc(T)=E=(365/(card(T)+5))*(nb/453.5924)*(TPIT(T)-PHR(T));

DMExcE(T)..    DMExc(T)=E=(nb/453.5924)*(SUM(J, DM(J)*Y(T,J))-
(WBPG(T)+0.195*DEI(T)+0.0996*SUM(J,
NDF(J)*Y(T,J))+0.0225*DBWG(T)));

SLGE..         SLG=G=39919+613.37*0.776*SUM(T, DMExc(T))/card(T);

NCLGE..        NCLG=E=0.2*SUM(T, NExc(T))/SLG;

SLG.LO=0.00001;

PCLGE..        PCLG=E=0.2*2.29*SUM(T, PExc(T))/SLG;

NPCE(pl)..     PCLG*MA(pl)=E=PTO(pl)*LD(pl);

MUTE..         SUM(pl, MA(pl))+MS=E=SLG;

CHOE..         CHO=E=0.4178*MS;

LACE..         SUM(pl, LD(pl))=L=10000;

CLGE..         CLG=E=30675+0.0798*SLG;

CMAE..         CMA=E=12510+218.3*SUM(pl, LD(pl));

LNCRE..        LNCR=E=((Pp*PCLG+Pn*NCLG)*SUM(pl, MA(pl))/0.08-
DT*(ihc+CLG+CMA+CHO))/nb;
```

```
CWF(T)..      FFLG(T)=E=2.55*WBPG(T);

IFFLE..       IFFL=E=453.59*0.95*(-3.65+0.418*44.09);

LPI..         LP=E=(SUM(T, FFLG(T))+IFFL)/(1000*FBW/1.35);

FBW.LO=20;

FBW.UP=120;

FBWI..        FBW=E=BW("94");

LP.LO=0.001;

PDI..         U1=E=EXP(-8.70976+29.29888*LP-24.13943*(LP**2));

WDI..         U2=E=-1.21112+0.03852*FBW-0.00016607*(FBW**2);

LGPI..        LGP=E=(((1+d)**card(T))/(((1+d)**card(T))-
1))*(Pb*U1*U2)*FBW/((1+d)**(card(T)-1));

LTCI..        LTC=E=(((1+d)**card(T))/(((1+d)**card(T))-1))*(Cf+SUM(T,
(CPTE(T)+SUM(J, Cg(J)*P(J)*Y(T,J)))/((1+d)**(ORD(T)-1))));

LFCI..        LVC=E=(((1+d)**card(T))/(((1+d)**card(T))-1))*SUM(T,
(CPTE(T)+SUM(J, Cg(J)*P(J)*Y(T,J)))/((1+d)**(ORD(T)-1)));

OBJ..         NPV=E=(LGP-LTC+LNCR);



MODEL PMG     OPTIMAL PIG PROBLEM    /ALL/;
SOLVE PMG USING NLP MAXIMIZING NPV;



file soln /C:\output1.txt/;
put soln;
put 'BW.L(T)'/;
loop (T, put BW.L(T)/);
put 'DBWG.L(T)'/;
loop (T, put DBWG.L(T)/);
put 'WBPG.L(T)'/;
loop (T, put WBPG.L(T)/);
put 'FFLG.L(T)'/;
loop (T, put FFLG.L(T)/);
```

```
put 'FSY.L(T)'/;
loop (T, put FSY.L(T)/);
put 'FTG.L(T)'/;
loop (T, put FTG.L(T)/);
put 'PTG.L(T)'/;
loop (T, put PTG.L(T)/);
put 'FFLG.L(T)'/;
loop (T, put FFLG.L(T)/);
put 'DEI.L(T)'/;
loop (T, put DEI.L(T)/);
put 'PHR.L(T)'/;
loop (T, put PHR.L(T)/);
put 'Pe.L(T)'/;
loop (T, put Pe.L(T)/);
put 'CAR.L(T)'/;
loop (T, put CAR.L(T)/);
put 'TNCont.L(T)'/;
loop (T, put TNCont.L(T)/);
put 'RAEN.L(T)'/;
loop (T, put RAEN.L(T)/);
put 'FI.L(T)'/;
loop (T, put FI.L(T)/);
put 'RANI.L(T)'/;
loop (T, put RANI.L(T)/);
put 'DET.L(T)'/;
loop (T, put DET.L(T)/);
put 'TPIT.L(T)'/;
loop (T, put TPIT.L(T)/);
put 'TNIT.L(T)'/;
loop (T, put TNIT.L(T)/);
put 'RAPI.L(T)'/;
loop (T, put RAPI.L(T)/);
put 'NExc.L(T)'/;
loop (T, put NExc.L(T)/);
put 'PExc.L(T)'/;
loop (T, put PExc.L(T)/);
put 'DMExc.L(T)'/;
loop (T, put DMExc.L(T)/);
put 'ARM.L(T, "lysine")'/;
loop (T, put ARM.L(T, "lysine")/);
put 'ARP.L(T, "lysine")'/;
loop (T, put ARP.L(T, "lysine")/);
put 'Y.L(T, "L-tryptophan")'/;
loop (T, put Y.L(T, "L-tryptophan")/);
put 'Y.L(T, "Corn")'/;
loop (T, put Y.L(T, "Corn")/);
```

```
put 'Y.L(T, "DL-methionine")'/;
loop (T, put Y.L(T, "DL-methionine")/);
put 'Y.L(T, "SBM")'/;
loop (T, put Y.L(T, "SBM")/);
put 'Y.L(T, "L-lysine ")'/;
loop (T, put Y.L(T, "L-lysine")/);
put 'Y.L(T, " L-threonine ")'/;
loop (T, put Y.L(T, "L-threonine")/);
put 'Y.L(T, "DicalciumP ")'/;
loop (T, put Y.L(T, "DicalciumP")/);
put 'Y.L(T, "LimstonG ")'/;
loop (T, put Y.L(T, "LimstonG")/);
put 'Y.L(T, "Casein")'/;
loop (T, put Y.L(T, "Casein")/);
put 'Y.L(T, "Cornstarch")'/;
loop (T, put Y.L(T, "Cornstarch")/);
put 'Y.L(T, "SPI")'/;
loop (T, put Y.L(T, "SPI")/);
```

APPENDIX B

The Detail Results of the Simulation Models

Table A- 1. The Simulated Results for Pigs with High Lean Growth Rate

D day	BW kg	DBWG g	WBPG g	FSY g	FTG g	PTG g	CFFLG g
1	20.00	719.56	112.39	168.96	187.73	488.65	286.60
2	20.72	732.13	114.10	172.89	192.10	496.10	290.96
3	21.45	744.66	115.80	176.86	196.52	503.46	295.28
4	22.20	757.13	117.47	180.87	200.97	510.74	299.55
5	22.95	769.54	119.12	184.91	205.45	517.92	303.76
6	23.72	781.88	120.75	188.98	209.97	525.00	307.91
7	24.50	794.13	122.35	193.07	214.52	531.97	312.00
8	25.30	806.29	123.93	197.18	219.09	538.83	316.02
9	26.11	818.35	125.48	201.31	223.68	545.57	319.97
10	26.92	830.29	127.00	205.46	228.29	552.18	323.86
11	27.75	842.12	128.50	209.62	232.91	558.67	327.66
12	28.60	853.81	129.96	213.79	237.55	565.03	331.39
13	29.45	865.36	131.39	217.97	242.19	571.26	335.04
14	30.32	876.77	132.79	222.14	246.83	577.34	338.61
15	31.19	888.03	134.15	226.32	251.47	583.28	342.09
16	32.08	899.12	135.49	230.49	256.10	589.07	345.49
17	32.98	910.05	136.79	234.65	260.72	594.72	348.80
18	33.89	920.80	138.05	238.80	265.33	600.22	352.03
19	34.81	931.37	139.28	242.93	269.93	605.56	355.16
20	35.74	941.75	140.47	247.05	274.50	610.75	358.20
21	36.68	951.94	141.63	251.14	279.04	615.78	361.16
22	37.64	961.94	142.75	255.21	283.56	620.66	364.02
23	38.60	971.73	143.84	259.25	288.05	625.38	366.78
24	39.57	981.32	144.89	263.25	292.50	629.94	369.46
25	40.55	990.70	145.90	267.22	296.92	634.34	372.04
26	41.54	999.87	146.88	271.16	301.29	638.59	374.53
27	42.54	1008.83	147.82	275.05	305.61	642.68	376.93
28	43.55	1017.56	148.72	278.90	309.89	646.62	379.24
29	44.57	1026.08	149.59	282.71	314.12	650.40	381.46
30	45.59	1034.38	150.43	286.46	318.29	654.03	383.59
31	46.63	1042.46	151.23	290.17	322.41	657.51	385.63
32	47.67	1050.32	151.99	293.82	326.47	660.84	387.58
33	48.72	1057.96	152.72	297.42	330.46	664.02	389.45
34	49.78	1065.37	153.42	300.96	334.40	667.06	391.23
35	50.84	1072.57	154.09	304.44	338.26	669.95	392.93
36	51.92	1079.55	154.72	307.86	342.06	672.71	394.54
37	53.00	1086.30	155.33	311.22	345.80	675.33	396.08
38	54.08	1092.85	155.90	314.51	349.46	677.82	397.54
39	55.17	1099.17	156.44	317.74	353.05	680.18	398.92
40	56.27	1105.29	156.95	320.91	356.56	682.41	400.23
41	57.38	1111.20	157.44	324.01	360.01	684.52	401.47
42	58.49	1116.90	157.90	327.04	363.38	686.51	402.64

Table A-1. *(Continue)*

D day	BW kg	DBWG g	WBPG g	FSY g	FTG g	PTG g	CFFLG g
43	59.61	1122.39	158.33	330.00	366.67	688.38	403.74
44	60.73	1127.69	158.73	332.90	369.89	690.15	404.77
45	61.86	1132.80	159.11	335.72	373.03	691.80	405.74
46	62.99	1137.71	159.47	338.48	376.09	693.35	406.65
47	64.13	1142.43	159.80	341.17	379.08	694.80	407.50
48	65.27	1146.97	160.12	343.80	382.00	696.16	408.30
49	66.42	1151.34	160.41	346.35	384.83	697.42	409.04
50	67.57	1155.53	160.68	348.84	387.60	698.60	409.73
51	68.72	1159.55	160.93	351.26	390.29	699.69	410.37
52	69.88	1163.41	161.16	353.61	392.90	700.70	410.96
53	71.05	1167.11	161.38	355.90	395.44	701.64	411.51
54	72.21	1170.66	161.58	358.12	397.92	702.50	412.02
55	73.39	1174.06	161.76	360.28	400.32	703.30	412.49
56	74.56	1177.33	161.93	362.38	402.65	704.04	412.92
57	75.74	1180.46	162.08	364.42	404.91	704.72	413.32
58	76.92	1183.46	162.23	366.40	407.11	705.34	413.68
59	78.10	1186.34	162.36	368.32	409.25	705.91	414.02
60	79.29	1189.10	162.48	370.19	411.32	706.44	414.32
61	80.48	1191.76	162.59	372.00	413.33	706.92	414.61
62	81.67	1194.31	162.69	373.76	415.29	707.36	414.87
63	82.86	1196.76	162.79	375.47	417.18	707.77	415.11
64	84.06	1199.13	162.87	377.13	419.03	708.15	415.33
65	85.26	1201.41	162.96	378.74	420.82	708.50	415.54
66	86.46	1203.61	163.03	380.31	422.56	708.83	415.73
67	87.66	1205.75	163.10	381.83	424.26	709.14	415.91
68	88.87	1207.82	163.17	383.32	425.91	709.44	416.08
69	90.08	1209.83	163.24	384.77	427.52	709.72	416.25
70	91.29	1211.80	163.30	386.19	429.10	709.99	416.41
71	92.50	1213.72	163.36	387.57	430.63	710.27	416.57
72	93.71	1215.61	163.42	388.92	432.13	710.54	416.73
73	94.93	1217.46	163.49	390.25	433.61	710.81	416.89
74	96.14	1219.30	163.55	391.55	435.05	711.09	417.06
75	97.36	1221.12	163.62	392.82	436.47	711.38	417.23
76	98.59	1222.93	163.69	394.08	437.87	711.69	417.41
77	99.81	1224.75	163.76	395.32	439.25	712.01	417.60
78	101.03	1226.57	163.84	396.55	440.61	712.36	417.80
79	102.26	1228.40	163.93	397.77	441.97	712.73	418.01
80	103.49	1230.25	164.02	398.98	443.31	713.13	418.25
81	104.72	1232.13	164.12	400.19	444.65	713.56	418.50
82	105.95	1234.05	164.22	401.39	445.99	714.02	418.77
83	107.18	1236.01	164.34	402.59	447.33	714.53	419.07
84	108.42	1238.02	164.47	403.80	448.67	715.07	419.39
85	109.66	1240.09	164.60	405.02	450.02	715.67	419.74

Table A-1. *(continue)*

D day	BW kg	DBWG g	WBPG g	FSY g	FTG g	PTG g	CFFLG g
86	110.90	1242.22	164.75	406.24	451.38	716.31	420.11
87	112.14	1244.43	164.91	407.49	452.76	717.00	420.52
88	113.39	1246.72	165.08	408.74	454.16	717.76	420.96
89	114.63	1249.09	165.27	410.02	455.58	718.57	421.44
90	115.88	1251.57	165.47	411.32	457.03	719.45	421.95
91	117.13	1254.14	165.69	412.65	458.50	720.39	422.51
92	118.39	1256.83	165.92	414.01	460.02	721.41	423.10
93	119.64	1259.64	166.17	415.41	461.57	722.50	423.75
94	120.90	1262.58	166.44	416.84	463.16	723.67	424.43
95	122.17	1265.66	166.73	418.32	464.80	724.92	425.17
96	123.43	1268.89	167.04	419.84	466.49	726.26	425.95
97	124.70	1272.27	167.37	421.41	468.23	727.70	426.79
98	125.97	1275.81	167.72	423.03	470.04	729.23	427.69
99	127.25	1279.53	168.10	424.71	471.91	730.85	428.65
100	128.53	1283.44	168.49	426.46	473.84	732.59	429.66

Table A- 2. Estimated Nutrient Requirements for Pigs with High Lean Growth Rate

D (days)	MxDEI (kcal)	DEM (kcal)	LysinM (g)	LysinG (g)	LysinT (g)	BPR (g)
1	4485.20	1040.32	0.34	13.49	13.83	3.75
2	4583.39	1068.26	0.35	13.69	14.04	3.78
3	4682.11	1096.45	0.36	13.90	14.25	3.81
4	4781.28	1124.87	0.37	14.10	14.46	3.84
5	4880.86	1153.53	0.38	14.29	14.67	3.87
6	4980.78	1182.42	0.39	14.49	14.88	3.90
7	5080.98	1211.53	0.40	14.68	15.08	3.93
8	5181.41	1240.85	0.41	14.87	15.28	3.96
9	5282.00	1270.40	0.42	15.06	15.47	3.99
10	5382.69	1300.15	0.43	15.24	15.67	4.02
11	5483.42	1330.11	0.44	15.42	15.85	4.05
12	5584.12	1360.26	0.45	15.59	16.04	4.07
13	5684.75	1390.61	0.46	15.77	16.22	4.10
14	5785.23	1421.15	0.47	15.93	16.40	4.13
15	5885.51	1451.86	0.48	16.10	16.57	4.15
16	5985.53	1482.75	0.49	16.26	16.74	4.18
17	6085.23	1513.81	0.50	16.41	16.91	4.20
18	6184.56	1545.04	0.51	16.57	17.07	4.23
19	6283.45	1576.42	0.52	16.71	17.23	4.25
20	6381.85	1607.95	0.53	16.86	17.38	4.27
21	6479.71	1639.62	0.54	17.00	17.53	4.30
22	6576.98	1671.43	0.55	17.13	17.68	4.32
23	6673.61	1703.37	0.56	17.26	17.82	4.34
24	6769.56	1735.43	0.57	17.39	17.95	4.36
25	6864.76	1767.61	0.58	17.51	18.09	4.38
26	6959.19	1799.90	0.59	17.63	18.21	4.40
27	7052.79	1832.30	0.60	17.74	18.34	4.42
28	7145.54	1864.79	0.61	17.85	18.46	4.44
29	7237.38	1897.37	0.62	17.95	18.57	4.46
30	7328.30	1930.04	0.63	18.05	18.68	4.48
31	7418.24	1962.79	0.64	18.15	18.79	4.49
32	7507.19	1995.61	0.65	18.24	18.89	4.51
33	7595.12	2028.50	0.66	18.33	18.99	4.52
34	7682.00	2061.45	0.67	18.41	19.09	4.54
35	7767.81	2094.45	0.69	18.49	19.18	4.55
36	7852.53	2127.50	0.70	18.57	19.26	4.57
37	7936.13	2160.60	0.71	18.64	19.35	4.58
38	8018.61	2193.73	0.72	18.71	19.43	4.59
39	8099.96	2226.89	0.73	18.77	19.50	4.60
40	8180.16	2260.08	0.74	18.83	19.57	4.62
41	8259.20	2293.29	0.75	18.89	19.64	4.63
42	8337.08	2326.52	0.76	18.95	19.71	4.64
43	8413.80	2359.76	0.77	19.00	19.77	4.65
44	8489.36	2393.01	0.78	19.05	19.83	4.66
45	8563.75	2426.26	0.79	19.09	19.89	4.66
46	8636.99	2459.51	0.80	19.14	19.94	4.67

Table A-2. ***(continue)***

D (days)	MxDEI (kcal)	DEM (kcal)	LysinM (g)	LysinG (g)	LysinT (g)	BPR (g)
47	8709.07	2492.75	0.82	19.18	19.99	4.68
48	8780.02	2525.98	0.83	19.21	20.04	4.69
49	8849.83	2559.20	0.84	19.25	20.09	4.69
50	8918.52	2592.40	0.85	19.28	20.13	4.70
51	8986.11	2625.58	0.86	19.31	20.17	4.70
52	9052.61	2658.74	0.87	19.34	20.21	4.71
53	9118.04	2691.86	0.88	19.37	20.25	4.71
54	9182.42	2724.96	0.89	19.39	20.28	4.72
55	9245.78	2758.03	0.90	19.41	20.31	4.72
56	9308.13	2791.05	0.91	19.43	20.34	4.73
57	9369.51	2824.04	0.92	19.45	20.37	4.73
58	9429.93	2856.99	0.94	19.47	20.40	4.73
59	9489.43	2889.90	0.95	19.48	20.43	4.74
60	9548.04	2922.76	0.96	19.50	20.45	4.74
61	9605.79	2955.57	0.97	19.51	20.48	4.74
62	9662.71	2988.34	0.98	19.52	20.50	4.74
63	9718.83	3021.05	0.99	19.53	20.52	4.75
64	9774.19	3053.72	1.00	19.54	20.54	4.75
65	9828.82	3086.33	1.01	19.55	20.56	4.75
66	9882.77	3118.90	1.02	19.56	20.58	4.75
67	9936.07	3151.40	1.03	19.57	20.60	4.75
68	9988.76	3183.86	1.04	19.58	20.62	4.75
69	10040.87	3216.26	1.05	19.59	20.64	4.75
70	10092.46	3248.60	1.06	19.60	20.66	4.75
71	10143.56	3280.89	1.07	19.60	20.68	4.75
72	10194.21	3313.13	1.08	19.61	20.70	4.76
73	10244.46	3345.31	1.09	19.62	20.71	4.76
74	10294.35	3377.43	1.11	19.63	20.73	4.76
75	10343.93	3409.51	1.12	19.63	20.75	4.76
76	10393.23	3441.53	1.13	19.64	20.77	4.76
77	10442.32	3473.50	1.14	19.65	20.79	4.76
78	10491.23	3505.42	1.15	19.66	20.81	4.76
79	10540.02	3537.29	1.16	19.67	20.83	4.76
80	10588.73	3569.11	1.17	19.68	20.85	4.76
81	10637.40	3600.88	1.18	19.69	20.87	4.76
82	10686.10	3632.61	1.19	19.71	20.90	4.76
83	10734.87	3664.30	1.20	19.72	20.92	4.76
84	10783.76	3695.95	1.21	19.74	20.95	4.77
85	10832.83	3727.55	1.22	19.75	20.97	4.77
86	10882.13	3759.12	1.23	19.77	21.00	4.77
87	10931.71	3790.66	1.24	19.79	21.03	4.77
88	10981.62	3822.17	1.25	19.81	21.06	4.77
89	11031.93	3853.64	1.26	19.83	21.09	4.78
90	11082.68	3885.09	1.27	19.86	21.13	4.78
91	11133.94	3916.52	1.28	19.88	21.16	4.78
92	11185.77	3947.93	1.29	19.91	21.20	4.79
93	11238.22	3979.32	1.30	19.94	21.24	4.79

Table A-2. ***(continue)***

D (days)	MxDEI (kcal)	DEM (kcal)	LysinM (g)	LysinG (g)	LysinT (g)	BPR (g)
94	11291.35	4010.70	1.31	19.97	21.29	4.79
95	11345.24	4042.08	1.32	20.01	21.33	4.80
96	11399.93	4073.44	1.33	20.04	21.38	4.80
97	11455.50	4104.81	1.34	20.08	21.43	4.81
98	11512.02	4136.18	1.35	20.13	21.48	4.81
99	11569.55	4167.56	1.36	20.17	21.54	4.82
100	11628.16	4198.95	1.37	20.22	21.59	4.83

Table A- 3. The Simulated Growth Level of Profit Maximization Model for Pigs with High Lean Growth Rate

D (day)	BW (kg)	DBWG (g)	WBPG (g)	FSY (g)	FTG (g)	PTG (g)	CFFLG (g)
1	20.00	633.28	103.10	132.31	147.01	448.27	262.91
2	20.63	648.37	105.32	136.41	151.57	457.90	268.56
3	21.28	663.53	107.53	140.59	156.21	467.51	274.20
4	21.95	678.75	109.73	144.83	160.92	477.10	279.82
5	22.62	694.01	111.93	149.13	165.70	486.67	285.43
6	23.32	709.31	114.12	153.50	170.56	496.19	291.02
7	24.03	724.62	116.30	157.93	175.47	505.66	296.57
8	24.75	739.93	118.47	162.41	180.46	515.08	302.09
9	25.49	755.23	120.62	166.95	185.50	524.42	307.57
10	26.25	770.50	122.75	171.53	190.59	533.68	313.00
11	27.02	785.73	124.86	176.16	195.74	542.85	318.38
12	27.80	800.91	126.94	180.84	200.93	551.93	323.70
13	28.60	816.02	129.00	185.55	206.17	560.89	328.96
14	29.42	831.05	131.04	190.30	211.45	569.74	334.15
15	30.25	845.99	133.05	195.09	216.76	578.47	339.27
16	31.10	860.82	135.02	199.90	222.11	587.06	344.31
17	31.96	875.52	136.97	204.73	227.48	595.52	349.27
18	32.83	890.10	138.88	209.58	232.87	603.82	354.14
19	33.72	904.53	140.76	214.45	238.28	611.98	358.93
20	34.63	918.81	142.60	219.33	243.70	619.98	363.62
21	35.55	932.92	144.40	224.22	249.13	627.81	368.21
22	36.48	946.85	146.16	229.10	254.56	635.48	372.71
23	37.43	960.60	147.88	233.99	259.99	642.97	377.10
24	38.39	974.15	149.57	238.87	265.41	650.28	381.39
25	39.36	987.49	151.21	243.74	270.83	657.42	385.58
26	40.35	1000.63	152.80	248.60	276.22	664.37	389.65
27	41.35	1013.54	154.36	253.44	281.60	671.13	393.62
28	42.36	1026.23	155.87	258.25	286.95	677.71	397.47
29	43.39	1038.68	157.34	263.04	292.27	684.09	401.22
30	44.43	1050.90	158.77	267.80	297.56	690.29	404.85
31	45.48	1062.86	160.15	272.52	302.80	696.29	408.37
32	46.54	1074.58	161.48	277.21	308.01	702.10	411.78
33	47.62	1086.05	162.78	281.85	313.17	707.72	415.08
34	48.70	1097.26	164.02	286.45	318.28	713.15	418.26
35	49.80	1108.21	165.23	291.00	323.33	718.39	421.34
36	50.91	1118.90	166.39	295.49	328.33	723.44	424.30
37	52.03	1129.32	167.51	299.93	333.26	728.30	427.15
38	53.16	1139.48	168.59	304.32	338.13	732.98	429.89
39	54.30	1149.37	169.62	308.64	342.93	737.48	432.53
40	55.45	1159.00	170.61	312.89	347.66	741.80	435.06

Table A-3. *(continue)*

D (day)	BW (kg)	DBWG (g)	WBPG (g)	FSY (g)	FTG (g)	PTG (g)	CFFLG (g)
41	56.60	1168.35	171.57	317.09	352.32	745.93	437.49
42	57.77	1177.44	172.48	321.21	356.90	749.90	439.82
43	58.95	1186.27	173.35	325.26	361.40	753.69	442.04
44	60.14	1194.82	174.18	329.24	365.82	757.32	444.17
45	61.33	1203.12	174.98	333.14	370.15	760.78	446.20
46	62.53	1211.15	175.74	336.96	374.40	764.08	448.13
47	63.75	1218.92	176.46	340.71	378.57	767.22	449.97
48	64.96	1226.44	177.15	344.38	382.64	770.21	451.73
49	66.19	1233.69	177.80	347.96	386.62	773.05	453.39
50	67.42	1240.70	178.42	351.46	390.52	775.74	454.97
51	68.66	1247.46	179.01	354.88	394.32	778.29	456.47
52	69.91	1253.97	179.56	358.22	398.02	780.71	457.89
53	71.17	1260.24	180.09	361.47	401.63	782.99	459.22
54	72.43	1266.26	180.58	364.63	405.15	785.14	460.49
55	73.69	1272.06	181.05	367.71	408.57	787.17	461.67
56	74.96	1277.62	181.49	370.70	411.89	789.07	462.79
57	76.24	1282.95	181.90	373.60	415.12	790.86	463.84
58	77.53	1288.06	182.28	376.42	418.25	792.53	464.82
59	78.81	1292.95	182.64	379.15	421.28	794.09	465.74
60	80.11	1297.62	182.98	381.79	424.21	795.55	466.59
61	81.40	1302.08	183.29	384.35	427.05	796.90	467.38
62	82.71	1306.34	183.58	386.82	429.80	798.16	468.12
63	84.01	1310.39	183.84	389.20	432.45	799.32	468.80
64	85.32	1314.24	184.09	391.50	435.00	800.39	469.43
65	86.64	1317.90	184.32	393.71	437.46	801.37	470.00
66	87.96	1321.37	184.52	395.84	439.82	802.27	470.53
67	89.28	1324.65	184.71	397.88	442.09	803.08	471.01
68	90.60	1327.76	184.88	399.84	444.27	803.82	471.44
69	91.93	1330.68	185.03	401.72	446.36	804.48	471.83
70	93.26	1333.43	185.17	403.52	448.35	805.07	472.17
71	94.59	1336.01	185.29	405.23	450.26	805.59	472.48
72	95.93	1338.43	185.39	406.87	452.08	806.04	472.75
73	97.27	1340.69	185.48	408.43	453.81	806.43	472.97
74	98.61	1342.79	185.56	409.91	455.46	806.76	473.17
75	99.95	1344.73	185.62	411.31	457.02	807.03	473.32
76	101.30	1346.53	185.67	412.64	458.49	807.25	473.45
77	102.64	1348.19	185.70	413.90	459.89	807.41	473.54
78	103.99	1349.70	185.73	415.08	461.20	807.52	473.61
79	105.34	1351.07	185.74	416.19	462.43	807.58	473.64
80	106.69	1352.32	185.75	417.23	463.59	807.59	473.65
81	108.04	1353.43	185.74	418.20	464.67	807.55	473.63
82	109.40	1354.41	185.72	419.10	465.67	807.48	473.59
83	110.75	1355.28	185.69	419.94	466.60	807.36	473.52

Table A-3. *(continue)*

D (day)	BW (kg)	DBWG (g)	WBPG (g)	FSY (g)	FTG (g)	PTG (g)	CFFLG (g)
84	112.11	1356.02	185.66	420.71	467.46	807.20	473.43
85	113.46	1356.65	185.61	421.42	468.24	807.01	473.31
86	114.82	1357.16	185.56	422.06	468.95	806.78	473.18
87	116.18	1357.57	185.50	422.64	469.60	806.51	473.02
88	117.53	1357.87	185.43	423.16	470.18	806.22	472.85
89	118.89	1358.06	185.35	423.62	470.69	805.89	472.65

Table A- 4. The Estimated Nutrient Requirements of Profit Maximization Model for Pigs with High Lean Growth Rate

D (days)	DEI (kcal)	LysinM (g)	LysinG (g)	LysinT (g)	BPR (g)	CAL (g)
1	3905.43	0.34	12.37	12.71	4.10	7.70
2	4008.02	0.35	12.64	12.99	4.21	7.80
3	4111.89	0.36	12.90	13.26	4.33	7.89
4	4216.96	0.37	13.17	13.54	4.45	7.99
5	4323.18	0.37	13.43	13.80	4.57	8.09
6	4430.49	0.38	13.69	14.07	4.69	8.19
7	4538.82	0.39	13.96	14.35	4.81	8.28
8	4648.09	0.40	14.22	14.62	4.94	8.38
9	4758.25	0.41	14.47	14.88	5.06	8.48
10	4869.21	0.42	14.73	15.15	5.19	8.57
11	4980.91	0.43	14.98	15.41	5.32	8.67
12	5093.27	0.44	15.23	15.67	5.45	8.77
13	5206.20	0.45	15.48	15.93	5.58	8.86
14	5319.65	0.45	15.72	16.17	5.72	8.96
15	5433.52	0.46	15.97	16.43	5.85	9.05
16	5547.74	0.47	16.20	16.67	5.99	9.15
17	5662.23	0.48	16.44	16.92	6.12	9.24
18	5776.91	0.49	16.67	17.16	6.26	9.33
19	5891.70	0.50	16.89	17.39	6.39	9.42
20	6006.53	0.51	17.11	17.62	6.53	9.51
21	6121.31	0.52	17.33	17.85	6.67	9.60
22	6235.97	0.53	17.54	18.07	6.81	9.69
23	6350.43	0.54	17.75	18.29	6.95	9.78
24	6464.62	0.56	17.95	18.51	7.09	9.86
25	6578.47	0.57	18.14	18.71	7.22	9.95
26	6691.90	0.58	18.34	18.92	7.36	10.03
27	6804.85	0.59	18.52	19.11	7.50	10.11
28	6917.25	0.60	18.70	19.30	7.64	10.19
29	7029.02	0.61	18.88	19.49	7.78	10.27
30	7140.12	0.62	19.05	19.67	7.92	10.34
31	7250.48	0.63	19.22	19.85	8.05	10.42
32	7360.03	0.64	19.38	20.02	8.19	10.49
33	7468.73	0.65	19.53	20.18	8.33	10.56
34	7576.52	0.66	19.68	20.34	8.46	10.63
35	7683.35	0.67	19.83	20.50	8.60	10.70
36	7789.18	0.69	19.97	20.66	8.73	10.76
37	7893.95	0.70	20.10	20.80	8.86	10.82
38	7997.62	0.71	20.23	20.94	9.00	10.89
39	8100.16	0.72	20.35	21.07	9.13	10.95
40	8201.53	0.73	20.47	21.20	9.26	11.00
41	8301.69	0.74	20.59	21.33	9.39	11.06
42	8400.61	0.75	20.70	21.45	9.52	11.11

Table A-4. *(continue)*

D (days)	DEI (kcal)	LysinM (g)	LysinG (g)	LysinT (g)	BPR (g)	CAL (g)
43	8498.26	0.77	20.80	21.57	9.64	11.17
44	8594.63	0.78	20.90	21.68	9.77	11.22
45	8689.67	0.79	21.00	21.79	9.89	11.27
46	8783.37	0.80	21.09	21.89	10.01	11.32
47	8875.72	0.81	21.18	21.99	10.13	11.36
48	8966.70	0.82	21.26	22.08	10.25	11.41
49	9056.28	0.84	21.34	22.18	10.37	11.45
50	9144.47	0.85	21.41	22.26	10.49	11.49
51	9231.25	0.86	21.48	22.34	10.60	11.53
52	9316.61	0.87	21.55	22.42	10.72	11.57
53	9400.54	0.88	21.61	22.49	10.83	11.60
54	9483.06	0.89	21.67	22.56	10.94	11.64
55	9564.14	0.91	21.73	22.64	11.05	11.67
56	9643.79	0.92	21.78	22.70	11.15	11.70
57	9722.02	0.93	21.83	22.76	11.26	11.73
58	9798.83	0.94	21.87	22.81	11.36	11.76
59	9874.21	0.95	21.92	22.87	11.46	11.79
60	9948.18	0.96	21.96	22.92	11.56	11.82
61	10020.75	0.98	21.99	22.97	11.66	11.84
62	10091.92	0.99	22.03	23.02	11.76	11.87
63	10161.70	1.00	22.06	23.06	11.85	11.89
64	10230.10	1.01	22.09	23.10	11.95	11.92
65	10297.14	1.02	22.12	23.14	12.04	11.94
66	10362.83	1.03	22.14	23.17	12.13	11.96
67	10427.17	1.05	22.17	23.22	12.22	11.98
68	10490.19	1.06	22.19	23.25	12.30	12.00
69	10551.91	1.07	22.20	23.27	12.39	12.02
70	10612.32	1.08	22.22	23.30	12.47	12.04
71	10671.46	1.09	22.23	23.32	12.55	12.06
72	10729.34	1.10	22.25	23.35	12.63	12.08
73	10785.98	1.12	22.26	23.38	12.71	12.10
74	10841.39	1.13	22.27	23.40	12.79	12.12
75	10895.59	1.14	22.27	23.41	12.87	12.14
76	10948.60	1.15	22.28	23.43	12.94	12.15
77	11000.44	1.16	22.28	23.44	13.01	12.17
78	11051.12	1.17	22.29	23.46	13.08	12.19
79	11100.67	1.18	22.29	23.47	13.15	12.21
80	11149.11	1.20	22.29	23.49	13.22	12.23
81	11196.45	1.21	22.29	23.50	13.29	12.24
82	11242.72	1.22	22.29	23.51	13.35	12.26
83	11287.93	1.23	22.28	23.51	13.42	12.28
84	11332.10	1.24	22.28	23.52	13.48	12.30
85	11375.26	1.25	22.27	23.52	13.54	12.32
86	11417.42	1.26	22.27	23.53	13.60	12.34

Table A-4. *(continue)*

D (days)	DEI (kcal)	LysinM (g)	LysinG (g)	LysinT (g)	BPR (g)	CAL (g)
87	11458.59	1.27	22.26	23.53	13.66	12.36
88	11498.81	1.29	22.25	23.54	13.72	12.39
89	11538.09	1.30	22.24	23.54	13.77	12.41

Table A- 5. The Optimal Ration Composition of Profit Maximization Model for Pigs with High Lean Growth Rate

	Wheat		SBM		LimstonG		
D (days)	Amount (g)	Percent	Amount (g)	Percent	Amount (g)	Percent	FI (g)
1	903.81	72.77	322.70	25.98	15.58	1.25	1242.09
2	931.08	73.03	328.07	25.73	15.71	1.23	1274.85
3	958.88	73.31	333.33	25.48	15.84	1.21	1308.05
4	987.23	73.58	338.46	25.23	15.97	1.19	1341.66
5	1016.10	73.86	343.46	24.97	16.10	1.17	1375.66
6	1045.48	74.15	348.32	24.70	16.23	1.15	1410.03
7	1075.37	74.43	353.03	24.44	16.36	1.13	1444.75
8	1105.74	74.72	357.57	24.16	16.49	1.11	1479.80
9	1136.60	75.01	361.95	23.89	16.62	1.10	1515.17
10	1167.92	75.31	366.15	23.61	16.75	1.08	1550.81
11	1199.69	75.61	370.16	23.33	16.87	1.06	1586.72
12	1231.88	75.91	373.99	23.04	17.00	1.05	1622.87
13	1264.49	76.21	377.62	22.76	17.13	1.03	1659.24
14	1297.49	76.51	381.05	22.47	17.25	1.02	1695.79
15	1330.87	76.82	384.27	22.18	17.37	1.00	1732.51
16	1364.60	77.12	387.28	21.89	17.50	0.99	1769.37
17	1398.66	77.43	390.07	21.59	17.62	0.98	1806.35
18	1433.03	77.74	392.65	21.30	17.74	0.96	1843.42
19	1467.69	78.05	395.00	21.00	17.85	0.95	1880.55
20	1502.61	78.35	397.13	20.71	17.97	0.94	1917.71
21	1537.78	78.66	399.04	20.41	18.08	0.92	1954.90
22	1573.16	78.97	400.72	20.12	18.19	0.91	1992.07
23	1608.73	79.28	402.18	19.82	18.30	0.90	2029.21
24	1644.46	79.59	403.41	19.52	18.41	0.89	2066.28
25	1680.34	79.89	404.42	19.23	18.51	0.88	2103.27
26	1716.34	80.20	405.21	18.93	18.62	0.87	2140.16
27	1752.42	80.50	405.77	18.64	18.71	0.86	2176.91
28	1788.58	80.80	406.12	18.35	18.81	0.85	2213.51
29	1824.77	81.10	406.26	18.06	18.91	0.84	2249.94
30	1860.98	81.40	406.19	17.77	19.00	0.83	2286.17
31	1897.19	81.70	405.91	17.48	19.09	0.82	2322.18
32	1933.36	81.99	405.43	17.19	19.17	0.81	2357.96
33	1969.48	82.29	404.75	16.91	19.25	0.80	2393.48
34	2005.52	82.57	403.89	16.63	19.33	0.80	2428.73
35	2041.45	82.86	402.83	16.35	19.41	0.79	2463.69
36	2077.27	83.15	401.60	16.07	19.48	0.78	2498.35
37	2112.93	83.43	400.19	15.80	19.55	0.77	2532.68
38	2148.43	83.70	398.62	15.53	19.62	0.76	2566.68
39	2183.75	83.98	396.89	15.26	19.69	0.76	2600.32
40	2218.86	84.25	395.00	15.00	19.75	0.75	2633.60
41	2253.74	84.52	392.96	14.74	19.81	0.74	2666.51

Table A-5. *(continue)*

	Wheat		SBM		LimstonG		
D (days)	Amount (g)	Percent	Amount (g)	Percent	Amount (g)	Percent	FI (g)
42	2288.38	84.79	390.78	14.48	19.86	0.74	2699.03
43	2322.77	85.05	388.47	14.22	19.91	0.73	2731.15
44	2356.87	85.31	386.03	13.97	19.96	0.72	2762.87
45	2390.68	85.56	383.47	13.72	20.01	0.72	2794.17
46	2424.19	85.81	380.80	13.48	20.05	0.71	2825.04
47	2457.38	86.06	378.02	13.24	20.10	0.70	2855.49
48	2490.23	86.30	375.14	13.00	20.14	0.70	2885.51
49	2522.74	86.54	372.16	12.77	20.17	0.69	2915.08
50	2554.90	86.78	369.10	12.54	20.20	0.69	2944.20
51	2586.68	87.01	365.96	12.31	20.24	0.68	2972.88
52	2618.09	87.24	362.74	12.09	20.27	0.68	3001.10
53	2649.12	87.46	359.46	11.87	20.29	0.67	3028.87
54	2679.75	87.68	356.11	11.65	20.32	0.66	3056.18
55	2709.99	87.90	352.70	11.44	20.34	0.66	3083.03
56	2739.81	88.11	349.25	11.23	20.36	0.65	3109.42
57	2769.23	88.32	345.74	11.03	20.38	0.65	3135.35
58	2798.23	88.53	342.20	10.83	20.40	0.65	3160.82
59	2826.80	88.73	338.62	10.63	20.41	0.64	3185.84
60	2854.96	88.93	335.01	10.44	20.42	0.64	3210.39
61	2882.68	89.12	331.38	10.25	20.44	0.63	3234.50
62	2909.98	89.31	327.72	10.06	20.45	0.63	3258.14
63	2936.84	89.50	324.04	9.88	20.46	0.62	3281.34
64	2963.27	89.68	320.35	9.70	20.47	0.62	3304.10
65	2989.27	89.86	316.66	9.52	20.48	0.62	3326.41
66	3014.84	90.04	312.95	9.35	20.49	0.61	3348.28
67	3039.97	90.21	309.24	9.18	20.49	0.61	3369.71
68	3064.67	90.38	305.54	9.01	20.50	0.60	3390.71
69	3088.95	90.55	301.83	8.85	20.51	0.60	3411.29
70	3112.79	90.71	298.14	8.69	20.52	0.60	3431.44
71	3136.21	90.87	294.45	8.53	20.53	0.59	3451.18
72	3159.20	91.03	290.77	8.38	20.53	0.59	3470.51
73	3181.78	91.18	287.11	8.23	20.54	0.59	3489.43
74	3203.93	91.33	283.46	8.08	20.55	0.59	3507.95
75	3225.68	91.48	279.84	7.94	20.56	0.58	3526.07
76	3247.01	91.62	276.23	7.79	20.57	0.58	3543.81
77	3267.94	91.77	272.64	7.66	20.58	0.58	3561.16
78	3288.46	91.90	269.08	7.52	20.60	0.58	3578.14
79	3308.59	92.04	265.55	7.39	20.61	0.57	3594.75
80	3328.33	92.17	262.04	7.26	20.63	0.57	3610.99
81	3347.68	92.30	258.55	7.13	20.64	0.57	3626.87
82	3366.64	92.43	255.10	7.00	20.66	0.57	3642.41
83	3385.23	92.55	251.67	6.88	20.69	0.57	3657.59
84	3403.45	92.68	248.28	6.76	20.71	0.56	3672.44

Table A-5. *(continue)*

	Wheat		SBM		LimstonG		
D (days)	Amount (g)	Percent	Amount (g)	Percent	Amount (g)	Percent	FI (g)
85	3421.30	92.79	244.92	6.64	20.74	0.56	3686.95
86	3438.79	92.91	241.59	6.53	20.77	0.56	3701.14
87	3455.92	93.03	238.29	6.41	20.80	0.56	3715.01
88	3472.71	93.14	235.03	6.30	20.83	0.56	3728.56
89	3489.14	93.25	231.80	6.19	20.87	0.56	3741.81

Table A- 6. The Ingredient Composition of Diets in Experiment 1 (on an as fed basis).

	Treatment[a]			
Ingredient, %	Diet 1 CS&Caesin	Diet 2 Corn+CSd&Caesin	Diet 3 CS&Caesin+SBM	Diet 4 Corn&SBM
Cornstarch	79.17	17.90	61.27	--
Casein	11.70	10.21	1.49	--
Corn	--	60.51	--	60.51
SBM-48	--	--	27.78	27.78
Soy oil	3.69	6.39	4.65	7.35
DL-Methionine	.08	.07	.12	.11
L-Lysine	.08	.07	.01	--
L-Threonine	.12	.11	.08	.06
L-Tryptophan	.04	.03	--	--
NaH2PO4	.04	.00	.15	.11
CaCO3	.47	.48	.15	.16
K2SO4	.75	.31	.51	.07
NaCl	.32	.27	.30	.25
NaHCO3	.55	.65	.50	.59
Phos mixb	2.0	2.0	2.0	2.0
Vit TM mixc	1.0	1.0	1.0	1.0

[a] Diet 1 = cornstarch and casein; Diet 2 = Diet 1 with corn replacing a portion of the cornstarch; Diet 3 = Diet 1 with SBM replacing most of casein; Diet 4 = fortified corn-SBM diet.
[b]Formulated to contain 40.5 percent NaH_2PO_4, 49.5 percent $CaCO_3$, and 10 percent MgCl.
[c]Vitamins and minerals met or exceeded NRC (1998) requirements.
[d] CS refers to cornstarch used in the experiment.

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 1999. "Effects of Corn and (or) Soybean Meal on Nitrogen and Phosphorus Excretion of Growing Pigs." *Oklahoma Animal Science Research Report*. pp280-286.

Table A- 7. The Nutrient Composition of the Diets in Experiment 1 (on an as-fed basis)

	Req.[d]	Treatment[a] Diet 1 CS&Caesin	Diet 2 Corn+CS[b]&Caesin	Diet 3 CS&Caesin+SBM	Diet 4 Corn&SBM
Calculated values					
ME, kcal/kg DM		4100	4100	4100	4100
DE, kcal/kg	3399	3973	3830	3943	3800
Nitrogen, %		2.00	2.46	2.91	3.14
CP, %		12.5	15.4	18.2	19.6
Total lys, %		0.85	0.92	0.92	0.98
Digestible AA, %					
Lysine	1.14	0.82	0.82	0.82	0.82
Arginine	0.46	0.36	0.51	0.95	1.11
Histidine	0.36	0.31	0.39	0.36	0.44
Isoleucine	0.62	0.50	0.59	0.60	0.68
Leucine	1.15	0.99	1.41	1.03	1.46
Methionine	0.31	0.38	0.43	0.33	0.37
TSAA [c]	0.65	0.49	0.49	0.49	0.49
Phenylalanine	0.68	0.53	0.68	0.66	0.80
Phe+tyrosine	1.07	1.07	1.28	1.18	1.39
Threonine	0.71	0.53	0.53	0.53	0.53
Tryptophan	0.21	0.15	0.15	0.15	0.15
Valine	0.77	0.67	0.79	0.64	0.76
Calcium, %		0.60	0.60	0.60	0.60
P, %	0.53	0.33	0.45	0.48	0.61
Avail P, %	0.22	0.31	0.31	0.31	0.31
Analyzed values					
Nitrogen, %		2.21	2.74	3.24	3.49
CP, %		13.8	17.1	20.3	21.8
P, %		0.38	0.45	0.54	0.68

[a] Diets were formulated to contain .82 percent digestible lysine and .31 percent available P. A constant ratio of Ca:available P (1.9:1) was maintained across treatments.
[b] CS refers to cornstarch used in the experiment.
[c] TSAA refers to total sulfur amino acids, which consist of methionine and cystine.
[d] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 1999. "Effects of Corn and (or) Soybean Meal on Nitrogen and Phosphorus Excretion of Growing Pigs." *Oklahoma Animal Science Research Report*. pp280-286.

Table A- 8. The Ingredient Composition of Diets in Experiment 2 (on an as fed basis).

	Treatment [a]			
Ingredient, percent	Diet 1 CS&SBM	Diet 2 CS&SBMH	Diet 3 CS&SPC	Diet 4 CS&SPI
Cornstarch	65.19	60.38	76.44	79.23
Soybean meal, 48%	29.52	28.75	--	--
Soybean hulls	--	4.11	--	--
Soy protein concentrate	--	--	19.26	--
Soy protein isolate	--	--	--	16.29
Soy oil	1.0	2.52	--	--
DL-methionine	.11	.11	.12	.13
L-threonine	.07	.07	--	.05
NaCl	.27	.27	.27	.27
Dical. Phosphate	1.37	1.37	1.37	1.45
$CaCO_3$	.57	.53	.65	.76
K_2SO_4	.46	.46	.46	.46
$NaHCO_3$	.90	.90	.88	.80
Vit, Min PM	.30	.30	.30	.30
Antibiotic	.25	.25	.25	.25

[a] Diet 1 contains soybean meal (SBM) as the single source of dietary protein. In Diet 2, soybean hulls were added and replaced a portion of soybean meal in diet 1 (SBMH). Soy protein concentrate (SPC) and soy protein isolate (SPI) was the only soy protein source in respective Diet 3 and Diet 4.

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2000. “Nitrogen and Phosphorus Excretion from Pigs Fed Different Soybean Fractions.” *Oklahoma Animal Science Research Report*. pp129-135.

Table A- 9. The Nutrient Composition of the Diets in Experiment 2 (on an as-fed basis)

		Treatment			
	Req.[b]	Diet 1 CS&SBM	Diet 2 CS&SBMH	Diet 3 CS&SPC	Diet 4 CS&SPI
Calculated values					
ME, Mcal/kg		3.4	3.4	3.4	3.4
DE, kcal/kg	3399	3783	3813	3847	3845
Percent Nitrogen		2.26	2.26	2.00	2.27
Percent CP		14.1	14.1	12.5	14.2
Percent total lysine		0.89	0.89	0.81	0.86
Percent Digestible AA					
Lysine	1.05	0.75	0.75	0.75	0.75
Arginine	0.46	0.97	0.96	1.10	1.02
Histidine	0.36	0.34	0.34	0.34	0.32
Isoleucine	0.62	0.57	0.56	0.60	0.62
Leucine	1.15	0.96	0.96	0.97	1.00
Methionine	0.31	0.29	0.29	0.28	0.29
TSAA	0.65	0.45	0.45	0.45	0.45
Phenylalanine	0.68	0.63	0.62	0.64	0.62
Phenylalanine+tyrosine	1.07	1.11	1.10	1.10	1.07
Threonine	0.71	0.49	0.49	0.49	0.49
Tryptophan	0.21	0.17	0.17	0.16	0.18
Valine	0.77	0.59	0.59	0.62	0.59
Percent Calcium		0.61	0.61	0.61	0.61
Percent total P	0.50	0.49	0.48	0.44	0.41
Percent available P	0.20	0.31	0.31	0.31	0.31
Analyzed values					
Percent Nitrogen		2.26	2.20	2.12	2.29
Percent CP		14.1	13.8	13.3	14.3
Percent total P		0.44	0.51	0.42	0.44

[a] TSAA refers to total sulfur amino acids, which consist of methionine and cystine.
[b] Digestible energy and [True] ileal digestible AA requirements, Table 10-1, NRC (1998).

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2000. "Nitrogen and Phosphorus Excretion from Pigs Fed Different Soybean Fractions." *Oklahoma Animal Science Research Report*. pp129-135.

Table A- 10. The Ingredient Composition of Diets in Experiment 3 (on an as fed basis).

	Treatment[a]			
Ingredients, Percent	Diet 1 Corn&SBM	Diet 2 LPAA	Diet 3 Corn&SBMH	Diet 4 Corn&SBMP
Corn, dent grain	71.12	72.22	71.56	71.63
SBM, dehulled	25.94	14.40	14.42	14.41
Soybean hulls	--	--	10.00	--
Beet pulp	--	--	--	10.00
Cornstarch	--	10.00	--	--
Soybean oil	1.00	1.00	1.00	1.00
Dicalcium phosphate	1.23	1.58	1.55	1.57
Salt	.25	.25	.25	.25
Vit/TM premix	.25	.25	.25	.25
Antibiotic	.20	.20	.20	.20
L-lysine HCl	--	.29	.35	.32
L-threonine	--	.15	.17	.16
DL-methionine	--	.12	.12	.11
L-tryptophan	--	.04	.05	.04
L-isoleucine	--	.02	.04	.03
L-valine	--	--	.04	.02

[a] Diet 1=fortified corn-soybean meal diet. Diet 2(LPAA) =Diet 1 with dietary crude protein reduced by 4 percent, and supplemented with synthetic Amino Acids. Diet 3=Diet 2 plus L-valine and soybean hulls (SBH) added at 10 percent of the diet. Diet 4=Diet 2 plus L-valine and dried beet pulp (DBP) added at 10 percent of the diet.

Source: Carter, S.D., A.L. Sutton, B.T. Richert, B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Effects of Adding Fiber Sources to Reduced-Crude Protein, Amino Acid-Supplemented Diets on Nitrogen Excretion, Growth Performance, and Carcass Traits of Finishing Pigs." *Journal of Animal Science*. 81:492-502.

Table A- 11. The Nutrient Composition of the Diets in Experiment 3 (on an as-fed basis)

	Req.[b]	Treatment Diet 1 Corn&SBM	Diet 2 LPAA	Diet 3 Corn&SBMH	Diet 4 Corn&SBMP
Calculated Analysis					
DE[a], kcal/kg	3399	3523	3532	3408	3416
Nitrogen, %		2.88	2.24	2.24	2.24
Crude Protein, %		18.00	14.00	14.00	14.00
Total Lysine, %		0.96	0.96	0.96	0.96
Digestible AA, %					
Lysine	0.99	0.78	0.82	0.80	0.78
Arginine	0.39	1.08	0.71	0.76	0.73
Histidine	0.32	0.44	0.31	0.33	0.33
Isoleucine	0.54	0.67	0.47	0.52	0.50
Leucine	1.00	1.49	1.13	1.17	1.15
Methionine	0.27	0.27	0.32	0.33	0.31
TSAA	0.56	0.51	0.55	0.54	0.53
Phenylalanine	0.59	0.80	0.56	0.59	0.57
Phenylalanine+tyrosine	0.93	1.38	0.96	1.00	0.99
Threonine	0.62	0.51	0.55	0.54	0.53
Tryptophan	0.18	0.16	0.16	0.16	0.15
Valine	0.67	0.76	0.53	0.60	0.57

[a]Calculated with the composition of rations, and the DE content of feedstuffs (NRC, 1998).
[b]Digestible energy and [True] ileal digestible AA requirements, Table 10-1, NRC (1998).

Source: Carter, S.D., A.L. Sutton, B.T. Richert, B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Effects of Adding Fiber Sources to Reduced-Crude Protein, Amino Acid-Supplemented Diets on Nitrogen Excretion, Growth Performance, and Carcass Traits of Finishing Pigs." *Journal of Animal Science*. 81:492-502.

Table A- 12. The Ingredient Composition of Diets in Experiment 4 (on an as fed basis).

Ingredient, percent	**Treatment**[a]			
	Diet 1 Corn&SBM	Diet 2 LPAA	Diet 3 Corn&SPC	Diet 4 Corn&SPI
Corn	67.01	77.90	83.44	86.09
Soybean meal, 48%	29.00	17.50	--	--
Soy protein concentrate	--	--	12.20	--
Soy protein isolate	--	--	--	8.85
Soy oil	1.50	1.30	1.0	1.20
Lysine HCl	--	0.27	0.24	0.30
DL-Methionine	--	0.06	0.05	0.07
L-Threonine	--	0.13	0.07	0.12
L-Tryptophan	--	0.03	0.03	0.03
L-Valine	--	0.02	--	--
Dicalcium Phosphate	0.95	1.03	1.00	1.08
$CaCO_3$	0.69	0.74	0.80	0.81
NaCl	0.25	0.25	0.25	0.25
K_2CO_3	--	0.17	0.32	0.60
Trace min/vit premix	0.30	0.30	0.30	0.30
Antibiotic	0.30	0.30	0.30	0.30

[a]Diet 1=fortified corn-soybean meal diet. Diet 2=Diet1 with dietary crude protein reduced by 4 percent, and supplemented with synthetic amino acids. Diet 3 and 4 were as Diet 2 with either soybean protein concentrate (SPC) or soy protein isolate (SPI) completely replacing SBM in Diet 2.

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Nitrogen Balance of Growing Pigs Fed Low Crude Protein,-Amino Acid Supplemented Diets with Different Soybean Products." Department of Animal Science, Oklahoma State University.

Table A- 13. The Nutrient Composition of the Diets in Experiment 4 (on an as-fed basis)

		Treatment			
	Req.[b]	Diet 1 Corn&SBM	Diet 2 LPAA	Diet 3 Corn&SPC	Diet 4 Corn&SPI
Calculated values					
DE[a], kcal/kg	3,399	3,431	3,391	3,457	3,424
Nitrogen, percent		3.10	2.46	2.46	2.46
CP, percent		19.40	15.40	15.40	15.40
Digestible AA, percent					
Lysine	1.04	0.92	0.84	0.84	0.82
Arginine	0.42	1.17	0.83	0.97	0.84
Histidine	0.33	0.47	0.36	0.38	0.35
Isoleucine	0.57	0.72	0.53	0.59	0.55
Leucine	1.05	1.55	1.28	1.37	1.32
Methionine	0.28	0.28	0.29	0.28	0.29
TSAA	0.59	0.58	0.47	0.48	0.47
Phenylalanine	0.62	0.85	0.65	0.70	0.64
Phenylalanine+tyrosine	0.97	1.48	1.11	1.17	1.08
Threonine	0.65	0.63	0.60	0.59	0.56
Tryptophan	0.19	0.20	0.17	0.17	0.17
Valine	0.70	0.81	0.63	0.67	0.61
Percent Total P	0.50	0.56	0.53	0.52	0.50
Analyzed values					
Percent Nitrogen		3.10	2.43	2.38	2.43
Percent CP		19.40	15.20	14.90	15.20
Percent total P		0.60	0.55	0.54	0.53

[a] Calculated with the composition of rations, and the DE content of feedstuffs (NRC, 1998).
[b] Digestible and True ileal digestible AA requirements, Table 10-1, NRC (1998).

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Nitrogen Balance of Growing Pigs Fed Low Crude Protein,-Amino Acid Supplemented Diets with Different Soybean Products." Department of Animal Science, Oklahoma State University.

Table A- 14. The Ingredient Composition of Diets in Experiment 5 (on an as fed basis).

Ingredient, percent	Treatment Diet 1 CS[a]&Casein	 Diet 2 Corn-SBM	 Diet 3 LPAA	 Diet 4 Corn&SPC
Corn	--	65.19	75.63	80.99
Cornstarch	80.89	--	--	--
Soybean meal, 48%	--	30.30	18.80	--
Soy protein concentrate	--	--	--	13.50
Caesin	12.61	--	--	--
Soy oil	2.00	2.00	2.00	2.00
Lysine HCl	--	--	0.28	0.22
DL-Methionine	--	--	0.10	0.06
L-Cystine	0.16	--	--	--
L-Threonine	0.10	--	0.13	0.05
L-Tryptophan	0.03	--	0.04	0.02
L-Valine	--	--	0.03	--
Dicalcium Phosphate	0.80	0.95	1.02	0.99
$CaCO_3$	1.08	0.71	0.77	0.82
NaCl	0.25	0.25	0.25	0.25
K_2CO_3	1.48	--	0.35	0.60
Trace min/vit premix[b, c]	0.30	0.30	0.30	0.30
Antibiotic	0.30	0.30	0.30	0.30

[a] CS refers to cornstarch used in the experiment.
[b] Formulated to contain 40.5 percent NaH_2PO_4, 49.5 percent $CaCO_3$, and 10 percent MgCl.
[c] Vitamins and minerals met or exceeded NRC (1998) requirements.

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Nitrogen Balance of Growing Pigs Fed Low Crude Protein,-Amino Acid Supplemented Diets with Different Soybean Products." Department of Animal Science, Oklahoma State University.

Table A- 15. The Nutrient Composition of the Diets in Experiment 5 (on an as-fed basis)

	Req.[a]	Treatment Diet 1 CS&Casein	 Diet 2 Corn-SBM	 Diet 3 LPAA	 Diet 4 Corn&SPC
Calculated values					
DE[b], kcal/kg	3399	3651	3415	3359	3423
Nitrogen, percent		3.07	2.43	2.43	1.76
CP, percent		19.20	15.20	15.20	11.00
Digestible AA, percent					
Lysine	1.07	0.88	0.96	0.88	0.87
Arginine	0.44	0.39	1.21	0.86	1.04
Histidine	0.34	0.34	0.48	0.37	0.40
Isoleucine	0.58	0.54	0.74	0.55	0.62
Leucine	1.08	1.06	1.58	1.30	1.42
Methionine	0.29	0.33	0.28	0.33	0.30
TSAA	0.61	0.50	0.59	0.48	0.50
Phenylalanine	0.64	0.57	0.87	0.67	0.73
Phenylalanine+tyrosine	1.00	1.15	1.52	1.14	1.23
Threonine	0.67	0.54	0.64	0.61	0.60
Tryptophan	0.19	0.16	0.21	0.19	0.17
Valine	0.72	0.72	0.83	0.66	0.71
Total P, percent	0.55	0.26	0.56	0.53	0.52
Analyzed values					
Nitrogen, percent		3.12	2.35	2.45	1.82
CP, percent		19.5	14.7	15.3	11.4
Total P, percent		0.19	0.56	0.49	0.47

[a] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[b] Calculated with the composition of rations, and the DE content of feedstuffs (NRC, 1998).

Source: Carter, S.D., B.W. Senne, L.A. Petty and J.A. Shriver. 2003. "Nitrogen Balance of Growing Pigs Fed Low Crude Protein,-Amino Acid Supplemented Diets with Different Soybean Products." Department of Animal Science, Oklahoma State University.

Table A- 16. The Ingredient Composition of Diets in Experiment 6 (on an as-fed basis)

Ingredient	Percent
CornA, B, C, or D[a]	90.48
Casein, dried	5.04
L-Lysine HCl	.50
DL-Methionine	.17
L-Threonine	.25
L-Tryptophan	.08
L-Isoleucine	.13
L-Valine	.04
Dicalcium phosphate	2.19
Limestone	.57
Salt	.25
Trace mineral or vitamin	.30

[a]Corn A, Corn B, Corn C and Corn D were added to constitute the four diets.

Source: Carter, S.D., J.S. Park, M.J. Rincker, and R.W. Fent. "Energy and Nitrogen Balance of Pigs Fed Four Corn Grains". 2001. *Animal Science Research Report*.

Table A- 17. The Nutrient Composition of the Grains and Diets in Experiment 6 (on an as-fed basis)

	Req.[a]	Treatment Diet 1 Corn A	Diet 2 Corn B	Diet 3 Corn C	Diet 4 Corn D
Calculated values					
Diet DE[b], kcal/kg	3,399	3398	3398	3398	3398
Diet N, percent		2.027	2.080	2.123	2.065
Diet CP, percent		12.67	13.00	13.27	12.90
Diet Total Lysine, percent		1.00	1.00	1.00	1.00
Diet Digestible AA, percent					
Lysine	1.07	1.18	1.31	1.36	1.30
Arginine	0.43	0.41	0.48	0.47	0.48
Histidine	0.34	0.30	0.33	0.33	0.33
Isoleucine	0.58	0.43	0.48	0.49	0.47
Leucine	1.08	0.91	0.95	0.97	0.97
Methionine	0.29	0.44	0.46	0.47	0.45
TSAA	0.61	0.40	0.40	0.40	0.40
Phenylalanine	0.64	0.53	0.59	0.60	0.58
Phe+tyrosine	1.00	0.97	0.97	0.97	0.97
Threonine	0.67	0.63	0.65	0.65	0.65
Tryptophan	0.19	0.10	0.09	0.09	0.09
Valine	0.72	0.63	0.68	0.69	0.70
Diet Calcium, percent		.80	.80	.80	.80
Diet Phosphorus, percent	0.53	.70	.70	.70	.70
Analyzed values					
Grain GE, kcal/kg DM		4,462	4,761	4,594	4,601
Diet GE, kcal/kg		3969	4223	4008	4030
Diet DE, kcal/kg		3517	3747	3584	3568
Grain N, percent		1.243	1.302	1.349	1.284
Grain CP, percent		7.77	8.13	8.43	8.03
Diet N, percent		1.991	2.030	2.108	2.080
Diet CP, percent		12.44	12.68	13.17	13.00

[a] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[b] Data on the DE contents of corn, sorghum, and casein was from NRC (1998).

Source: Carter, S.D., J.S. Park, M.J. Rincker, and R.W. Fent. "Energy and Nitrogen Balance of Pigs Fed Four Corn Grains." 2001. *Animal Science Research Report*.

Table A- 18. The Ingredient Composition of Diets in Experiment 7 (on an as-fed basis)

Ingredient	Percent
Corn HA, HB, HC[a]	90.48
Casein, dried	5.04
L-Lysine HCl	.50
DL-Methionine	.17
L-Threonine	.25
L-Tryptophan	.08
L-Isoleucine	.13
L-Valine	.04
Dicalcium phosphate	2.19
Limestone	.57
Salt	.25
Trace mineral or vitamin	.30

[a] Corn Hybrids A, B, and C were added to constitute the four diets.

Source: Carter, S.D., J.S. Park, M.J. Rincker, and R.W. Fent. "Determination of the Metabolizable Energy Concentration of Three Corn Hybrids Fed to Growing Pigs." 2000 *Animal Science Research Report*. pp123-128.

Table A- 19. The Nutrient Composition of the Grains and Diets in Experiment 7 (on an as-fed basis[a])

	Req.[b]	Treatment Diet 1 Corn Hybrid A	Diet 2 Corn Hybrid B	Diet 3 Corn Hybrid C
Calculated values				
Diet DE[c], kcal/kg	3,399	3,398	3,398	3,398
Diet N, percent		1.924	1.897	1.907
Diet CP, percent		12.03	11.86	11.92
Percent diet total lysine		1.00	1.00	1.00
Percent diet digestible AA				
Lysine	1.07	0.94	0.94	0.94
Arginine	0.44	0.45	0.46	0.44
Histidine	0.34	0.31	0.30	0.29
Isoleucine	0.59	0.57	0.57	0.44
Leucine	1.09	1.16	1.15	1.29
Methionine	0.29	0.46	0.46	0.46
TSAA	0.61	0.40	0.40	0.40
Phenylalanine	0.64	0.53	0.53	0.53
Phenylalanine+tyrosine	1.01	0.97	0.97	0.96
Threonine	0.67	0.61	0.62	0.63
Tryptophan	0.20	0.16	0.16	0.16
Valine	0.73	0.64	0.64	0.63
Diet Calcium, percent		.80	.80	.80
Diet P, percent	0.53	.70	.70	.70
Analyzed values				
Grain GE, kcal/kg DM		4,349	4,323	4,467
Diet GE, kcal/kg		3,488	3,469	3,480
Diet DE, kcal/kg		3,464	3,485	3,430
Grain N, percent		1.129	1.099	1.111
Grain CP, percent		7.06	6.87	6.94
Diet N, percent		2.042	1.948	1.981
Diet CP, percent		12.76	12.18	12.38

[a] All data were on a dry matter basis in the original report. The energy and nitrogen concentrations reported above are on an as-fed basis after adjusting for moisture content, except those labeled DM.
[b] True ileal digestible AA requirements, Table 10-1, NRC (1998).
[c]Data on the DE contents of corns was from NRC (1998).

Source: Carter, S.D., J.S. Park, M.J. Rincker, and R.W. Fent. "Determination of the Metabolizable Energy Concentration of Three Corn Hybrids Fed to Growing Pigs." 2000 *Animal Science Research Report*. pp123-128.

Table A- 20. The Ingredient Composition of Diets in Experiment 8 (on an as-fed basis)

Ingredient	Percent
Corn, red or white sorghum[a]	90.00
Casein, dried	6.14
L-Lysine HCl	.50
DL-Methionine	.14
L-Threonine	.19
L-Tryptophan	.08
L-Isoleucine	.10
L-Valine	.03
Dicalcium phosphate	1.61
Limestone	.66
Salt	.25
Trace mineral or vitamin	.30

[a]Corn, red sorghum, and white sorghum were added to constitute the three diets.

Source: Carter, S.D., B.K. Senne, M.J. Rincker, and R.W. Fent. "Energy and Nitrogen Balance of Pigs Commercial Red Sorghum, Identity-Preserved White Sorghum, or Corn." 2001 *Animal Science Research Report*. Oklahoma State University.

Table A- 21. The Nutrient Composition of the Grains and Diets in Experiment 8 (on an as-fed basis[a])

	Req.[d]	Treatment Diet 1 Corn&Caesin	Diet 2 RS[b]&Caesin	Diet 3 WS[c]&Caesin
Calculated values				
Diet DE[e], kcal/kg	3,399	3,426	3,296	3,296
Diet N, percent		2.235	2.380	2.382
Diet CP, percent		13.97	14.87	14.89
Percent diet total lysine		1.08	1.08	1.08
Percent diet digestible AA				
Lysine	1.07	0.99	1.00	0.97
Arginine	0.43	0.50	0.48	0.47
Histidine	0.34	0.35	0.33	0.31
Isoleucine	0.58	0.59	0.66	0.66
Leucine	1.08	1.39	1.50	1.54
Methionine	0.29	0.44	0.43	0.45
TSAA	0.61	0.31	0.40	0.30
Phenylalanine	0.64	0.61	0.67	0.67
Phe+tyrosine	1.00	0.82	0.89	0.89
Threonine	0.67	0.61	0.65	0.65
Tryptophan	0.19	0.17	0.20	0.19
Valine	0.73	0.70	0.79	0.78
Diet Calcium		.70	.70	.70
Diet Phosphorus	0.53	.60	.60	.60
Analyzed values				
GrainGE, kcal/kgDM		4,495	4,379	4,420
Diet GE, kcal/kg		3,910	3,891	3,892
Diet DE, kcal/kg		3,539	3,300	3,352
Grain N, percent DM		1.495	1.676	1.680
Grain CP, percent		8.31	9.32	9.34
Diet N, percent		2.142	2.353	2.363
Diet CP, percent		13.39	14.71	14.77

[a] All data were on a dry matter basis in the original report. The energy and nitrogen concentrations reported above are on an as-fed basis after adjusting for moisture content, except those labeled DM.
[b] RS refers to red sorghum used in the experiment.
[c] WS refers to white sorghum used in the experiment.
[d] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).
[e] Data on digestible energy of corn, sorghum, and casein was from NRC (1998).

Source: Carter, S.D., B.K. Senne, M.J. Rincker, and R.W. Fent. "Energy and Nitrogen Balance of Pigs Commercial Red Sorghum, Identity-Preserved White Sorghum, or Corn." 2001 *Animal Science Research Report*. Oklahoma State University.

Table A- 22. The Ingredient Composition of Diets in Experiment 9 (on an as-fed basis)

Ingredient	**Percent**
Ground corn	66.65
Soybean meal, dehulled	30.68
Dicalcium Phosphate	1.09
Limestone	.83
Salt	.25
Trace Vit/Min premix	.25
Antibiotic	.20
Cornstarch[a, b]	.05

[a]Cornstarch was added to the daily rations to provide 100 or 200 kcal/kg ME in Diets 2 and 3.
[b]Hemicell® replaced cornstarch in Diet 4 and provided 89 million IU/ton.

Source: Carter, S.D., B.K. Senne, and L.A. Pettey. "Effects of Hemicell® Addition to Corn-Soybean Meal Diets on Energy and Nitrogen Balance in Growing Pigs." 2000 *Animal Science Research Report*. pp 117-122. Oklahoma State University.

Table A- 23. The Nutrient Composition of the Diets in Experiment 9 (on an as-fed basis)

Calculated values	Req.[c]	Treatment[b] Diet 1 Corn&SBM	Diet 2 CS1+Corn&SBM	Diet 3 CS2+Corn&SBM	Diet 4 Corn&SBM+Hl
GE, kcal/kg		3934	4116	4197	3923
DE[a], kcal/kg	3399	3462	3669	3740	3456
Diet N, percent		3.002	2.876	2.876	2.851
CP, percent		18.76	17.98	17.98	17.82
Percent ttotal P	0.52	0.60	0.60	0.60	0.60
Digestible AA (percent)					
Lysine	1.03	0.97	0.95	0.92	0.97
Arginine	0.42	1.22	1.19	1.16	1.22
Histidine	0.33	0.49	0.48	0.47	0.49
Isoleucine	0.56	0.75	0.73	0.72	0.75
Leucine	1.04	1.61	1.57	1.53	1.61
Methionine	0.28	0.29	0.28	0.28	0.29
TSAA	0.59	0.60	0.58	0.57	0.60
Phenylalanine	0.62	0.89	0.86	0.84	0.89
Phe+tyrosine	0.97	1.54	1.50	1.46	1.54
Threonine	0.65	0.65	0.64	0.62	0.65
Tryptophan	0.19	0.21	0.21	0.20	0.21
Valine	0.70	0.84	0.82	0.80	0.84

[a] Calculated with the composition of rations, and the DE content of feedstuffs (NRC, 1998).
[b]Diet 1 = fortified corn-SBM diet; Diet 2 = Diet 1 plus 100 kcal/kg ME from cornstarch; Diet 3 = Diet 1 plus 200 kcal/kg ME from cornstarch; Diet 4 = Diet 1 plus Hemicell® at .05 %.
[c] Digestible energy and True ileal digestible AA requirements, Table 10-1, NRC (1998).

Source: Carter, S.D., B.K. Senne, and L.A. Pettey. "Effects of Hemicell® Addition to Corn-Soybean Meal Diets on Energy and Nitrogen Balance in Growing Pigs." 2000 *Animal Science Research Report*. pp 117-122. Oklahoma State University.

Table A- 24. The Ingredient and Nutrient Composition of Diets in Experiment 10 (on an as-fed basis)

		Treatments[a]						
	Req.[c]	Diet 1 CornSBM	Diet 2 CornSBM	Diet 3 CornSBM	Diet 4 CornSBM	Diet 5 CornSBMPT1	Diet 6 CornSBMPT2	Diet 7 CornSBMPT3
Ingredient (percent)								
Corn		72.07	72.07	72.07	72.07	72.07	72.07	72.07
Soybean meal		25.25	25.25	25.25	25.25	25.25	25.25	25.25
Corn starch		1.16	0.78	0.39	0.00	1.14	1.11	1.06
Monosodium phosphate		0.00	0.21	0.43	0.66	0.00	0.00	0.00
Limestone		0.82	0.99	1.16	1.32	0.82	0.82	0.82
Sodium chloride		0.25	0.25	0.25	0.25	0.25	0.25	0.25
TM & premix[a]		0.25	0.25	0.25	0.25	0.25	0.25	0.25
Antibiotic		0.20	0.20	0.20	0.20	0.20	0.20	0.84
SSF phytase[b]		0.00	0.00	0.00	0.00	0.03	0.05	0.10
Calculated values								
CP, percent		17.98	17.98	17.98	17.98	17.98	17.98	17.98
Lysine, percent		0.95	0.95	0.95	0.95	0.95	0.95	0.95
Ca, percent		0.41	0.47	.53	.59	.41	.41	.41
Total P, percent	0.50	0.34	0.39	.44	.49	.34	.34	.34
Available P, percent	0.19	0.07	0.12	.17	.22	.07	.07	.07
Phytase, PU/kg		0	0	0	0	250	500	1000
Analyzed Total P, percent		0.37	0.43	0.48	0.52	0.37	0.37	0.37

[a] Provided the following per kg of diet: 5,506 IU of vitamin A, 551 IU of vitamin D, 33 IU of vitamin E, 3.6 mg of vitamin K (as menadione), 221 mg of biotin, 137 mg of choline, 33.04 mg of niacin, 24.78 mg of panthothenic acid (as d-pantothenate), 5.51 mg of riboflavin, 27.55 mg of vitamin B12, 1.66 mg of folacin, 100 mg of Zn, 2 mg of Mn, 100 mg of Fe, 10 mg of Cu, .30 mg of I, and .30 mg of Se.
[b] Solid-state fermented phytase (Allzyme® SSF; Alltech, Inc) contains 1,000 PU/g of product.
[c] Total and available phosphorus requirements, Table 3-2, NRC (1998).

Source: Carter, S.D., J.D. Schneider, J.S. Park, and T.B. Morillo. “Effects of Solid-State Fermented Phytase on Phosphorus Utilization in Growing Pigs Fed Corn-Soybean Meal Diets: I. Growth Performance and Phosphorus Excretion.” 2003 *Animal Science Research Report*. Oklahoma State University.

Table A- 25. **The Results of Experimental, and Calculated Values of Simulation Model.**

		Experiment				Simulation			
	INIBW[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 1									
Diet 1:									
CS&Caesin	29.62	626.0	21.0	1132	0.553	952.80	22.70	1651.86	0.577
CS&Caesin	26.31	771.0	24.1	1269	0.608	897.38	21.63	1532.08	0.586
CS&Caesin	35.15	671.0	23.1	1240	0.541	1030.25	24.12	1830.35	0.563
CS&Caesin	27.03	789.0	26.6	1398	0.564	910.19	21.88	1559.26	0.584
CS&Caesin	33.57	871.0	27.7	1434	0.607	1009.76	23.76	1781.69	0.567
CS&Caesin	28.35	708.0	29.5	1572	0.450	932.43	22.32	1607.17	0.580
Mean	30.01	739.3	25.3	1341	0.554	955.47	22.74	1660.40	0.576
Diet 2:									
Corn+CS&Caesin	33.02	934.0	32.8	1643	0.568	1002.43	23.62	1830.51	0.548
Corn+CS&Caesin	28.49	971.0	32.8	1582	0.614	934.67	22.36	1672.29	0.559
Corn+CS&Caesin	31.25	744.0	28.1	1428	0.521	977.47	23.17	1771.00	0.552
Corn+CS&Caesin	21.18	962.0	33.1	1579	0.609	794.77	19.54	1373.24	0.579
Corn+CS&Caesin	30.35	934.0	31.5	1551	0.602	963.96	22.91	1739.42	0.554
Mean	28.86	909.0	31.6	1557	0.583	934.66	22.32	1677.29	0.558
Diet 3:									
CS&Caesin+SBM	30.62	798.0	33.3	1403	0.569	968.07	22.99	1698.99	0.570
CS&Caesin+SBM	26.72	1025.0	36.0	1474	0.695	904.63	21.78	1559.40	0.580
CS&Caesin+SBM	31.84	562.0	25.7	986	0.570	985.99	23.32	1739.95	0.567
CS&Caesin+SBM	30.57	789.0	30.8	1351	0.584	967.39	22.98	1697.45	0.570
CS&Caesin+SBM	31.89	1034.0	38.3	1559	0.663	986.63	23.34	1741.44	0.567
Mean	30.33	841.6	32.8	1355	0.616	962.54	22.88	1687.44	0.571
Diet 4:									
Corn&SBM	31.66	971.0	35.2	1620	0.599	983.39	23.28	1799.30	0.547
Corn&SBM	22.14	1116.0	30.0	1376	0.811	815.60	19.98	1427.18	0.571
Corn&SBM	26.13	880.0	29.7	1220	0.721	894.12	21.57	1594.92	0.561
Corn&SBM	26.63	372.0	35.5	1630	0.228	903.03	21.74	1614.61	0.559
Corn&SBM	30.62	844.0	30.6	1441	0.586	968.07	22.99	1763.01	0.549
Corn&SBM	32.61	971.0	40.5	1673	0.580	996.82	23.52	1831.59	0.544
Mean	28.30	859.0	33.6	1493	0.588	926.84	22.18	1671.77	0.555
Exp. Mean	29.37	837.2	30.8	1436	0.585	944.88	22.53	1674.23	0.565

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Table A-25. *(continue)*

	INIBW[a]	Experiment ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	Simulation ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 2									
Diet 1:									
CS&SBM	45.35	1058.0	29.4	1874	0.565	1135.52	25.87	2207.99	0.514
CS&SBM	31.75	982.0	23.0	1473	0.667	984.61	23.30	1810.26	0.544
CS&SBM	44.44	944.0	28.2	1841	0.513	1127.74	25.75	2185.27	0.516
CS&SBM	34.01	944.0	25.6	1567	0.602	1015.67	23.86	1886.05	0.539
CS&SBM	41.27	1398.0	29.4	1936	0.722	1098.29	25.28	2101.93	0.523
CS&SBM	30.16	793.0	23.0	1435	0.553	961.12	22.86	1754.52	0.548
Mean	37.83	1019.8	26.4	1688	0.604	1053.82	24.49	1991.00	0.531
Diet 2:									
CS&SBMH	43.76	1096.0	24.7	1604	0.683	1121.73	25.66	2150.88	0.522
CS&SBMH	30.84	1133.0	27.2	1784	0.635	971.37	23.05	1764.70	0.550
CS&SBMH	37.19	1020.0	24.0	1784	0.572	1054.71	24.55	1969.58	0.535
CS&SBMH	39.00	982.0	26.1	1744	0.563	1074.93	24.89	2022.46	0.531
CS&SBMH	42.18	1322.0	28.7	2017	0.655	1107.07	25.42	2109.65	0.525
CS&SBMH	33.56	1058.0	23.3	1618	0.654	1009.68	23.76	1856.52	0.544
Mean	37.76	1101.8	25.7	1759	0.627	1056.58	24.55	1978.97	0.535
Diet 3:									
CS&SPC	32.65	907.0	27.4	1800	0.504	997.37	23.53	1810.30	0.551
CS&SPC	36.05	1096.0	24.3	1561	0.702	1041.32	24.32	1918.04	0.543
CS&SPC	38.10	1360.0	29.1	1892	0.719	1065.00	24.72	1978.47	0.538
CS&SPC	39.46	831.0	23.4	1552	0.535	1079.77	24.97	2017.14	0.535
CS&SPC	34.01	907.0	22.5	1634	0.555	1015.67	23.86	1854.50	0.548
CS&SPC	34.47	793.0	19.4	1247	0.636	1021.55	23.97	1868.90	0.547
Mean	35.79	982.3	24.4	1614	0.609	1036.78	24.23	1907.89	0.544
Diet 4:									
CS&SPI	36.28	982.0	20.9	1319	0.745	1044.05	24.36	1925.92	0.542
CS&SPI	30.61	1020.0	18.5	1143	0.892	967.99	22.99	1741.98	0.556
CS&SPI	31.29	907.0	23.8	1402	0.647	978.05	23.18	1765.48	0.554
CS&SPI	42.18	907.0	23.9	1487	0.610	1107.07	25.42	2091.91	0.529
CS&SPI	38.10	1096.0	31.3	1772	0.619	1065.00	24.72	1979.51	0.538
CS&SPI	38.10	869.0	25.0	1484	0.586	1065.00	24.72	1979.51	0.538
Mean	36.09	963.5	23.9	1435	0.683	1037.86	24.23	1914.05	0.543
Exp. Mean	36.87	1016.9	25.1	1624	0.631	1046.26	24.38	1947.98	0.538

Table A-25. *(continue)*

	INIBW[a]	Experiment ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	Simulation ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 3									
Diet 1:									
Corn&SBM	34.06	1206.3	33.7	1913	0.631	1016.26	23.87	2026.81	0.501
Corn&SBM	37.41	784.8	34.3	1779	0.441	1057.32	24.59	2138.98	0.494
Corn&SBM	41.54	1011.8	36.1	1995	0.507	1100.96	25.32	2264.97	0.486
Corn&SBM	42.27	985.8	41.4	2040	0.483	1107.94	25.44	2285.88	0.485
Corn&SBM	44.13	940.4	36.3	2027	0.464	1124.95	25.71	2337.88	0.481
Corn&SBM	44.22	1135.0	30.7	2035	0.558	1125.75	25.72	2340.36	0.481
Mean	40.60	1010.7	35.4	1965	0.514	1088.86	25.11	2232.48	0.488
Diet 2:									
LPAA	31.97	1504.7	32.3	1998	0.753	987.84	23.36	1947.35	0.507
LPAA	37.82	968.5	29.4	1954	0.496	1061.95	24.67	2146.66	0.495
LPAA	38.82	895.0	32.2	2003	0.447	1072.97	24.86	2177.88	0.493
LPAA	40.68	895.0	29.5	1806	0.495	1092.41	25.18	2234.11	0.489
LPAA	41.81	836.7	23.7	1664	0.503	1103.60	25.37	2267.21	0.487
LPAA	42.31	1589.0	33.6	2197	0.723	1108.37	25.44	2281.50	0.486
Mean	38.90	1114.8	30.1	1937	0.570	1071.19	24.81	2175.78	0.493
Diet 3:									
Corn&SBMH	36.78	933.9	29.8	1788	0.522	1049.96	24.47	2189.84	0.479
Corn&SBMH	37.14	933.9	31.4	1863	0.501	1054.19	24.54	2202.00	0.479
Corn&SBMH	37.28	1154.5	32.1	1793	0.644	1055.75	24.57	2206.53	0.478
Corn&SBMH	37.51	985.8	34.8	1992	0.495	1058.35	24.61	2214.05	0.478
Corn&SBMH	43.85	1186.9	31.9	1996	0.595	1122.54	25.67	2408.92	0.466
Corn&SBMH	44.31	1013.9	34.8	1870	0.542	1126.55	25.73	2421.77	0.465
Mean	39.48	1034.8	32.4	1884	0.550	1077.89	24.93	2273.85	0.474
Diet 4:									
Corn&SBMP	34.97	940.4	24.8	1563	0.602	1027.90	24.08	2122.30	0.48
Corn&SBMP	37.37	1316.6	35.5	1998	0.659	1056.80	24.58	2204.26	0.48
Corn&SBMP	40.00	1122.0	28.5	1939	0.579	1085.46	25.07	2288.63	0.47
Corn&SBMP	41.50	1199.9	34.4	1969	0.609	1100.51	25.32	2334.33	0.47
Corn&SBMP	41.86	976.1	37.9	2111	0.462	1104.03	25.37	2345.16	0.47
Corn&SBMP	42.68	966.4	33.9	1952	0.495	1111.78	25.50	2369.22	0.47
Mean	39.73	1086.9	32.5	1922	0.568	1081.08	24.99	2277.32	0.475
Exp. Mean	39.68	1061.8	32.6	1927	0.550	1079.76	24.96	2239.86	0.483

Table A-25. ***(continue)***

		Experiment				Simulation			
	INIBW[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 4									
Diet 1:									
Corn&SBM	38.23	917.3	21.3	1401	0.655	1078.00	24.92	2259.37	0.477
Corn&SBM	33.06	957.6	23.0	1522	0.629	1026.71	24.25	2090.52	0.491
Corn&SBM	37.60	816.5	21.2	1387	0.589	1072.24	24.85	2239.72	0.479
Corn&SBM	32.88	977.8	23.5	1463	0.668	1024.72	24.22	2084.22	0.492
Corn&SBM	32.15	745.9	22.3	1440	0.518	1016.60	24.11	2058.71	0.494
Corn&SBM	28.25	877.0	21.2	1330	0.659	968.78	23.41	1913.57	0.506
Mean	33.70	882.0	22.1	1424	0.620	1031.18	24.29	2107.68	0.490
Diet 2:									
LPAA	38.10	1139.0	22.2	1679	0.678	1076.78	24.91	2281.72	0.472
LPAA	28.12	806.4	20.7	1412	0.571	966.97	23.38	1930.70	0.501
LPAA	36.73	836.6	24.3	1640	0.510	1064.20	24.75	2238.61	0.475
LPAA	34.24	1038.2	24.8	1690	0.614	1039.33	24.42	2155.94	0.482
LPAA	31.66	766.1	21.7	1449	0.529	1010.88	24.02	2064.92	0.490
LPAA	31.52	887.0	21.9	1668	0.532	1009.31	24.00	2059.97	0.490
Mean	33.39	912.2	22.6	1590	0.572	1027.91	24.25	2121.98	0.485
Diet 3:									
Corn&SPC	32.06	866.9	18.5	1332	0.651	1015.57	24.09	2039.61	0.498
Corn&SPC	37.14	776.2	20.2	1597	0.486	1068.04	24.80	2208.31	0.484
Corn&SPC	33.61	695.5	21.8	1514	0.460	1032.61	24.33	2093.00	0.493
Corn&SPC	31.97	907.2	19.3	1399	0.648	1014.53	24.08	2036.41	0.498
Corn&SPC	26.94	614.9	17.7	1245	0.494	950.92	23.13	1846.99	0.515
Corn&SPC	31.52	997.9	22.2	1651	0.604	1009.31	24.00	2020.29	0.500
Mean	32.21	809.8	20.0	1456	0.557	1015.16	24.07	2040.77	0.498
Diet 4:									
Corn&SPI	37.41	927.4	17.2	1283	0.723	1070.57	24.83	2238.76	0.478
Corn&SPI	29.39	776.2	21.3	1473	0.527	983.44	23.63	1961.33	0.501
Corn&SPI	32.20	877.0	21.5	1475	0.595	1017.11	24.11	2064.66	0.493
Corn&SPI	34.78	836.6	20.7	1478	0.566	1044.96	24.49	2153.64	0.485
Corn&SPI	32.79	1028.2	21.1	1505	0.683	1023.71	24.21	2085.44	0.491
Corn&SPI	26.30	745.9	19.2	1390	0.537	941.96	22.99	1839.40	0.512
Mean	32.15	865.2	20.2	1434	0.605	1013.63	24.04	2057.21	0.493
Exp. Mean	32.86	867.3	21.2	1476	0.589	1021.97	24.16	2081.91	0.492

Table A-25. ***(continue)***

		Experiment				Simulation			
	INIBW[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 5									
Diet 1:									
CS&Caesin	23.67	703.0	26.4	1745	0.403	902.31	22.36	1620.10	0.557
CS&Caesin	20.73	438.4	22.8	1496	0.293	852.56	21.52	1493.62	0.571
CS&Caesin	16.24	589.6	21.9	1422	0.415	764.23	19.95	1280.44	0.597
CS&Caesin	20.91	672.8	25.2	1648	0.408	855.80	21.58	1501.69	0.570
CS&Caesin	24.13	703.0	21.9	1459	0.482	909.44	22.47	1638.70	0.555
CS&Caesin	20.86	574.5	24.1	1711	0.336	854.99	21.56	1499.68	0.570
Mean	21.09	613.6	23.7	1580	0.389	856.56	21.57	1505.70	0.570
Diet 2:									
Corn&SBM	26.49	884.4	29.9	1790	0.494	944.54	23.03	1851.73	0.510
Corn&SBM	26.67	816.4	25.7	1890	0.432	947.11	23.07	1859.15	0.509
Corn&SBM	24.67	763.5	36.1	1736	0.440	917.84	22.61	1775.56	0.517
Corn&SBM	22.40	914.6	28.4	1597	0.573	881.61	22.01	1675.17	0.526
Corn&SBM	21.81	944.8	34.6	1846	0.512	871.63	21.85	1648.07	0.529
Corn&SBM	14.88	619.8	36.6	1351	0.459	734.03	19.39	1294.05	0.567
Mean	22.82	823.9	31.9	1702	0.485	882.79	21.99	1683.95	0.526
Diet 3:									
LPAA	26.49	1133.9	21.4	1853	0.612	944.54	23.03	1882.47	0.502
LPAA	24.31	703.0	27.1	1839	0.382	912.26	22.52	1789.11	0.510
LPAA	22.63	604.7	24.8	1806	0.335	885.38	22.08	1713.46	0.517
LPAA	22.81	876.8	21.0	1641	0.534	888.38	22.13	1721.80	0.516
LPAA	21.95	740.8	24.7	1663	0.446	873.95	21.89	1681.82	0.520
LPAA	19.95	514.0	21.4	1191	0.432	838.54	21.28	1585.63	0.529
Mean	23.02	762.2	23.4	1666	0.457	890.51	22.15	1729.05	0.515
Diet 4:									
Corn&SPC	22.90	846.6	28.4	1628	0.520	889.87	22.15	1693.68	0.525
Corn&SPC	27.48	695.4	28.5	1487	0.468	958.42	23.25	1887.58	0.508
Corn&SPC	24.26	922.2	28.9	1948	0.473	911.56	22.51	1753.69	0.520
Corn&SPC	22.95	846.6	23.7	1622	0.522	890.61	22.16	1695.71	0.525
Corn&SPC	22.31	914.6	26.7	1795	0.510	880.09	21.99	1667.00	0.528
Corn&SPC	23.99	491.3	17.4	1759	0.279	907.32	22.44	1741.86	0.521
Mean	23.98	786.1	25.6	1706	0.462	906.31	22.42	1739.92	0.521
Exp. Mean	22.73	746.4	26.2	1663	0.448	884.04	22.04	1664.66	0.533

Table A-25. *(continue)*

	INIBW[a]	Experiment ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	Simulation ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 6									
Diet 1:									
CornA	24.63	681.7	17.3	1144	0.596	838.80	20.46	1593.03	0.527
CornA	28.80	881.6	20.6	1473	0.599	914.05	21.96	1769.45	0.517
CornA	31.43	381.7	14.4	1044	0.366	955.54	22.76	1871.54	0.511
CornA	35.83	1272.5	21.6	1647	0.772	1016.22	23.87	2028.40	0.501
CornA	32.93	1018.0	22.0	1648	0.618	977.33	23.16	1926.77	0.507
CornA	30.43	636.2	16.9	1287	0.495	940.30	22.47	1833.59	0.513
Mean	30.67	812.0	18.8	1374	0.574	940.37	22.45	1837.13	0.512
Diet 2:									
CornB	34.56	863.5	21.5	1597	0.541	999.73	23.58	1863.06	0.537
CornB	30.11	827.1	16.2	1200	0.689	935.32	22.37	1709.61	0.547
CornB	26.62	645.3	18.9	1282	0.503	876.34	21.22	1576.72	0.556
CornB	20.73	363.6	12.8	860	0.423	756.08	18.72	1323.41	0.571
CornB	33.15	599.9	16.3	1190	0.504	980.53	23.22	1816.29	0.540
CornB	30.25	936.2	18.3	1387	0.675	937.46	22.41	1714.56	0.547
Mean	29.24	705.9	17.3	1253	0.556	914.24	21.92	1667.28	0.550
Diet 3:									
CornC	36.78	1208.8	22.5	1639	0.738	1028.08	24.08	2025.73	0.508
CornC	19.18	563.5	16.1	995	0.566	719.52	17.93	1309.66	0.549
CornC	26.17	772.6	20.0	1328	0.582	868.07	21.05	1632.60	0.532
CornC	31.16	818.0	18.7	1260	0.649	951.44	22.68	1830.09	0.520
CornC	35.28	1063.4	23.0	1569	0.678	1009.25	23.75	1976.19	0.511
CornC	28.84	781.7	18.9	1275	0.613	914.80	21.97	1741.58	0.525
Mean	29.57	868.0	19.9	1344	0.638	915.19	21.91	1752.64	0.524
Diet 4:									
CornD	27.80	490.8	18.6	1274	0.385	897.17	21.63	1704.73	0.526
CornD	28.57	481.7	9.7	765	0.630	910.27	21.89	1735.68	0.524
CornD	21.54	372.7	11.0	811	0.459	774.50	19.12	1429.50	0.542
CornD	33.11	954.4	16.6	1209	0.790	979.89	23.21	1906.25	0.514
CornD	37.96	1108.9	25.4	1805	0.614	1042.19	24.33	2069.35	0.504
CornD	30.20	690.8	17.7	1218	0.567	936.75	22.40	1799.28	0.521
Mean	29.86	683.2	16.5	1180	0.574	923.46	22.10	1774.13	0.522
Exp. Mean	29.84	767.3	18.1	1288	0.585	923.32	22.09	1757.80	0.527

Table A-25. ***(continue)***

	INIBW[a]	Experiment ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	Simulation ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 7									
Diet 1:									
CornHA	23.58	454.5	11.5	920	0.494	817.95	20.03	1572.70	0.520
CornHA	24.04	90.9	14.0	1015	0.090	827.12	20.22	1593.71	0.519
CornHA	27.66	636.2	16.7	1127	0.564	894.81	21.58	1753.23	0.510
CornHA	29.48	272.7	16.7	1246	0.219	925.19	22.18	1827.64	0.506
CornHA	31.29	272.7	18.2	1294	0.211	953.50	22.72	1898.79	0.502
CornHA	35.37	636.2	17.8	1348	0.472	1010.42	23.77	2047.89	0.493
CornHA	32.43	409.0	13.9	1061	0.386	970.21	23.03	1941.68	0.500
Mean	29.12	396.0	15.5	1145	0.348	914.17	21.93	1805.09	0.507
Diet 2:									
CornHB	32.88	681.7	12.8	1057	0.645	976.69	23.15	1941.67	0.503
CornHB	22.68	363.6	12.9	971	0.374	799.08	19.63	1516.76	0.527
CornHB	28.34	409.0	16.5	1187	0.345	906.46	21.81	1766.22	0.513
CornHB	27.44	136.3	13.6	1025	0.133	890.86	21.50	1728.70	0.515
CornHB	31.07	181.8	15.0	1210	0.150	950.06	22.65	1888.88	0.503
CornHB	31.97	590.8	16.4	1218	0.485	963.61	22.91	1908.12	0.505
CornHB	28.12	272.7	12.8	1163	0.234	902.61	21.74	1756.92	0.514
CornHB	24.94	272.7	14.2	1049	0.260	844.97	20.58	1620.95	0.521
Mean	28.43	363.6	14.3	1110	0.328	904.29	21.75	1766.03	0.513
Diet 3:									
CornHC	29.48	181.8	13.4	1110	0.164	925.19	22.18	1843.63	0.502
CornHC	22.68	363.6	12.7	1087	0.334	799.08	19.63	1543.29	0.518
CornHC	23.58	363.6	15.7	1132	0.321	817.95	20.03	1586.45	0.516
CornHC	29.48	454.5	15.9	1365	0.333	925.19	22.18	1843.63	0.502
CornHC	29.02	90.9	12.5	972	0.093	917.80	22.03	1825.18	0.503
CornHC	36.73	272.7	16.1	1279	0.213	1027.53	24.07	2120.51	0.485
CornHC	32.20	454.5	16.6	1336	0.340	966.92	22.97	1950.10	0.496
CornHC	29.48	363.6	17.1	1244	0.292	925.19	22.18	1843.63	0.502
Mean	29.08	318.1	15.0	1191	0.261	913.11	21.91	1819.55	0.503
Exp. Mean	28.88	359.2	14.9	1148	0.313	910.52	21.86	1796.89	0.508

Table A-25. *(continue)*

	INIBW[a]	Experiment ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	Simulation ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 8									
Diet 1:									
Corn&Caesin	22.09	344.7	14.6	974	0.354	750.97	18.61	1391.44	0.540
Corn&Caesin	23.81	571.4	19.1	1221	0.468	787.53	19.39	1470.47	0.536
Corn&Caesin	18.55	426.3	11.5	811	0.526	668.01	16.80	1218.46	0.548
Corn&Caesin	26.49	517.0	19.2	1246	0.415	839.84	20.48	1586.91	0.529
Corn&Caesin	27.26	553.3	19.0	1235	0.448	853.97	20.77	1619.13	0.527
Corn&Caesin	32.29	480.7	21.4	1484	0.324	937.11	22.41	1816.01	0.516
Corn&Caesin	34.24	634.9	30.0	1805	0.352	965.47	22.94	1886.47	0.512
Corn&Caesin	27.94	771.0	25.3	1551	0.497	866.12	21.01	1647.08	0.526
Corn&Caesin	29.48	598.6	22.3	1431	0.418	892.55	21.54	1708.83	0.522
Corn&Caesin	31.88	625.9	22.3	1452	0.431	930.92	22.29	1800.87	0.517
Corn&Caesin	33.02	571.4	24.0	1429	0.400	947.90	22.61	1842.59	0.514
Mean	27.91	554.1	20.8	1331	0.4211	858.22	20.80	1635.30	0.526
Diet 2:									
RS&Caesin	27.76	680.3	23.7	1372	0.496	862.91	20.95	1758.40	0.491
RS&Caesin	27.57	653.1	24.8	1535	0.425	859.68	20.88	1750.42	0.491
RS&Caesin	27.66	244.9	15.8	1054	0.232	861.30	20.91	1754.42	0.491
RS&Caesin	22.00	725.6	24.5	1358	0.534	748.98	18.57	1487.64	0.503
RS&Caesin	25.62	607.7	23.3	1391	0.437	823.56	20.14	1662.47	0.495
RS&Caesin	28.12	562.4	27.1	1531	0.367	869.31	21.08	1774.26	0.490
RS&Caesin	35.83	798.2	30.4	1825	0.437	987.14	23.35	2082.22	0.474
RS&Caesin	26.67	671.2	21.6	1335	0.503	843.20	20.55	1710.01	0.493
RS&Caesin	18.32	453.5	14.5	938	0.484	662.30	16.67	1294.24	0.512
RS&Caesin	35.60	698.4	26.1	1629	0.429	984.12	23.29	2073.89	0.475
RS&Caesin	23.54	299.3	14.0	861	0.348	781.91	19.27	1563.80	0.500
RS&Caesin	38.46	662.1	27.5	1654	0.400	1020.46	23.95	2175.82	0.469
Mean	28.10	588.1	22.8	1374	0.424	858.74	20.80	1757.30	0.490
Diet 3:									
WS&Caesin	24.13	535.1	18.1	1069	0.501	794.01	19.53	1567.24	0.507
WS&Caesin	18.55	390.0	14.7	870	0.448	668.01	16.80	1286.23	0.519
WS&Caesin	22.49	580.5	21.5	1211	0.479	759.84	18.80	1488.90	0.510
WS&Caesin	29.16	761.9	19.1	1217	0.626	887.23	21.43	1790.64	0.495
WS&Caesin	23.58	517.0	20.3	1228	0.421	782.85	19.29	1541.47	0.508
WS&Caesin	31.25	780.0	23.0	1498	0.521	921.11	22.10	1875.88	0.491
WS&Caesin	27.26	743.8	25.6	1472	0.505	853.97	20.77	1727.02	0.494
WS&Caesin	31.75	580.5	22.6	1396	0.416	928.84	22.25	1895.67	0.490
WS&Caesin	30.07	644.0	26.5	1662	0.387	902.28	21.73	1828.20	0.494
WS&Caesin	30.25	771.0	27.1	1756	0.439	905.23	21.79	1835.62	0.493
WS&Caesin	29.84	761.9	18.1	1131	0.674	898.56	21.66	1818.88	0.494
WS&Caesin	29.39	689.3	24.1	1440	0.479	891.04	21.51	1800.10	0.495
Mean	27.31	646.3	21.7	1329	0.491	849.41	20.64	1704.65	0.499
Exp. Mean	27.77	596.1	21.8	1345	0.446	855.46	20.75	1699.08	0.505

Table A-25. *(continue)*

		Experiment				Simulation			
	INIBW[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 9-1[b]									
Diet 1:									
Corn&SBM	37.64	861.7	24.7	1586	0.543	992.87	23.45	1999.82	0.496
Corn&SBM	33.56	952.4	25.4	1436	0.663	936.87	22.40	1855.70	0.505
Corn&SBM	32.65	816.3	22.1	1374	0.594	923.32	22.14	1821.96	0.507
Corn&SBM	28.12	861.7	21.1	1287	0.670	848.83	20.66	1643.05	0.517
Corn&SBM	23.58	1043.1	25.1	1414	0.738	761.55	18.84	1445.51	0.527
Mean	31.11	907.0	23.7	1419	0.642	892.69	21.50	1753.21	0.510
Diet 2:									
CS1+Corn&SBM	36.73	907.0	24.4	1596	0.568	981.09	23.23	1857.77	0.528
CS1+Corn&SBM	29.48	816.3	24.1	1457	0.560	872.43	21.14	1602.74	0.544
CS1+Corn&SBM	33.56	725.6	17.7	1338	0.542	936.87	22.40	1751.01	0.535
CS1+Corn&SBM	24.94	907.0	28.9	1490	0.609	789.22	19.43	1421.86	0.555
CS1+Corn&SBM	30.39	907.0	22.3	1337	0.679	887.54	21.44	1636.82	0.542
Mean	31.02	852.6	23.5	1444	0.592	893.43	21.53	1654.04	0.541
Diet 3:									
CS2+Corn&SBM	38.10	725.6	29.1	1654	0.439	998.62	23.56	1865.30	0.535
CS2+Corn&SBM	32.20	907.0	23.9	1500	0.605	916.39	22.01	1670.68	0.549
CS2+Corn&SBM	36.28	907.0	21.8	1412	0.642	975.06	23.12	1807.96	0.539
CS2+Corn&SBM	28.57	952.4	22.7	1316	0.724	856.82	20.82	1538.22	0.557
CS2+Corn&SBM	24.49	907.0	30.3	1539	0.590	780.14	19.23	1376.12	0.567
Mean	31.93	879.8	25.5	1484	0.600	905.41	21.75	1651.66	0.549
Diet 4:									
Corn&SBM+Hl	38.55	907.0	24.4	1552	0.584	1004.29	23.66	2033.73	0.494
Corn&SBM+Hl	35.83	725.6	22.6	1397	0.519	968.94	23.01	1940.65	0.499
Corn&SBM+Hl	31.75	907.0	17.1	1366	0.664	909.35	21.87	1790.66	0.508
Corn&SBM+Hl	26.76	861.7	19.2	1292	0.667	824.10	20.15	1588.60	0.519
Corn&SBM+Hl	22.22	680.3	17.7	1438	0.473	732.51	18.21	1384.64	0.529
Mean	31.02	816.3	20.2	1409	0.582	887.84	21.38	1747.66	0.510
Exp. Mean	31.27	863.9	23.2	1439	0.604	894.84	21.54	1701.64	0.528

Table A-25. *(continue)*

		Experiment				Simulation			
		ADG[a]	ADNR[a]	ADFI[a]	G:F[a]	ADG[a]	ADNR[a]	ADFI[a]	G:F[a]
Experiment 9-2[c]									
Diet 1:									
Corn&SBM	43.08	831.4	24.4	1698	0.490	1181.03	26.54	2565.87	0.460
Corn&SBM	36.73	982.6	29.6	1691	0.581	1127.66	25.75	2387.57	0.472
Corn&SBM	46.26	1020.4	26.1	1744	0.585	1202.56	26.84	2644.27	0.455
Corn&SBM	40.82	1020.4	30.1	1951	0.523	1163.69	26.29	2505.72	0.464
Corn&SBM	34.01	1020.4	24.9	1636	0.624	1099.63	25.30	2300.82	0.478
Mean	40.18	975.1	27.0	1744	0.560	1154.91	26.15	2480.85	0.466
Diet 2:									
CS1+Corn&SBM	45.80	944.8	31.8	1830	0.516	1199.67	26.80	2484.88	0.483
CS1+Corn&SBM	37.64	982.6	29.9	1801	0.546	1136.25	25.88	2278.75	0.499
CS1+Corn&SBM	40.82	907.0	27.9	1941	0.467	1163.69	26.29	2364.35	0.492
CS1+Corn&SBM	39.46	793.7	26.6	1778	0.446	1152.41	26.13	2328.58	0.495
CS1+Corn&SBM	34.01	907.0	26.1	1798	0.505	1099.63	25.30	2171.01	0.507
Mean	39.55	907.0	28.4	1830	0.496	1150.33	26.08	2325.52	0.495
Diet 3:									
CS2+Corn&SBM	45.35	1133.8	30.2	2000	0.567	1196.71	26.76	2427.59	0.493
CS2+Corn&SBM	41.27	793.7	24.8	1808	0.439	1167.30	26.35	2330.88	0.501
CS2+Corn&SBM	45.35	1020.4	30.0	1950	0.523	1196.71	26.76	2427.59	0.493
CS2+Corn&SBM	33.56	982.6	27.1	1697	0.579	1094.61	25.22	2115.78	0.517
CS2+Corn&SBM	38.10	944.8	26.8	1862	0.507	1140.41	25.95	2247.95	0.507
Mean	40.73	975.1	27.8	1863	0.523	1159.15	26.21	2309.95	0.502
Diet 4:									
Corn&SBM+Hl	47.62	944.8	32.6	1892	0.499	1210.90	26.95	2680.60	0.452
Corn&SBM+Hl	43.08	944.8	26.8	1851	0.510	1181.03	26.54	2570.33	0.459
Corn&SBM+Hl	40.82	1096.0	30.3	2043	0.537	1163.69	26.29	2510.07	0.464
Corn&SBM+Hl	35.37	944.8	24.8	1674	0.564	1114.08	25.53	2349.13	0.474
Corn&SBM+Hl	29.02	831.4	26.4	1545	0.538	1037.96	24.26	2125.78	0.488
Mean	39.18	952.4	28.2	1801	0.530	1141.53	25.92	2447.18	0.467
Exp. Mean	39.91	952.4	27.8	1809	0.527	1151.48	26.09	2390.88	0.483

[a] INIBW is the initial body weight in kg. ADNR is the average daily nitrogen retention in grams per day. ADFI is the average daily feed intake in grams per day. G:F is the efficiency of feed utilization (ADG/ADFI).

[b]Data concerning Experiment 9-1 corresponds to the first collection period of the experiment 9.

[c]Data concerning Experiment 9-2 corresponds to the second collection period of the experiment 9.

Table A- 26. Difference between the Simulated and Actual Phosphorus Retention.

	INIBW[a]	Simulation PHR(1)	PHR(2)[b]	Experiment	Difference[c]
Experiment 1					
Diet 1:					
CS&Caesin	29.6	4.243	3.174	3.017	-0.157
CS&Caesin	26.3	4.098	3.695	3.408	-0.287
CS&Caesin	35.2	4.438	3.289	3.048	-0.241
CS&Caesin	27.0	4.132	4.029	3.739	-0.290
CS&Caesin	33.6	4.388	3.808	4.214	0.407
CS&Caesin	28.4	4.190	4.466	4.151	-0.315
Diet 2:					
Corn+CS&Caesin	28.5	4.196	4.290	3.731	-0.559
Corn+CS&Caesin	33.0	4.369	4.233	4.030	-0.203
Corn+CS&Caesin	31.3	4.306	3.742	3.180	-0.562
Corn+CS&Caesin	21.2	3.816	4.829	3.687	-1.142
Corn+CS&Caesin	30.3	4.272	4.141	3.554	-0.587
Diet 3:					
CS&Caesin+SBM	31.9	4.330	4.186	4.836	0.650
CS&Caesin+SBM	30.6	4.281	3.672	3.655	-0.017
CS&Caesin+SBM	26.7	4.117	4.221	4.588	0.367
CS&Caesin+SBM	30.6	4.282	3.837	3.976	0.139
CS&Caesin+SBM	31.8	4.328	2.656	2.946	0.290
Diet 4:					
Corn-SBM	26.1	4.089	3.381	4.392	1.011
Corn-SBM	26.6	4.113	4.485	5.859	1.375
Corn-SBM	31.7	4.321	4.198	5.672	1.474
Corn-SBM	22.1	3.874	4.090	4.780	0.690
Corn-SBM	30.6	4.282	3.799	5.490	1.691
Corn-SBM	32.6	4.355	4.291	6.939	2.648

Table A-26. *(continue)*

	INIBW[a]	Simulation PHR(1)	PHR(2)[b]	Experiment	Difference[c]
Experiment 2					
Diet 1:					
CS-SBM	34.0	4.402	3.925	5.260	1.335
CS-SBM	44.4	4.666	4.196	6.240	2.044
CS-SBM	31.7	4.324	3.775	4.010	0.235
CS-SBM	41.3	4.600	4.478	4.890	0.412
CS-SBM	30.2	4.265	3.769	4.870	1.101
CS-SBM	45.4	4.684	4.229	5.320	1.091
Diet 2:					
CS-SBMH	30.8	4.291	4.632	6.170	1.538
CS-SBMH	43.8	4.653	3.692	6.000	2.308
CS-SBMH	37.2	4.497	4.356	5.350	0.994
CS-SBMH	33.6	4.387	4.090	5.240	1.150
CS-SBMH	42.2	4.620	4.676	6.180	1.504
CS-SBMH	39.0	4.545	4.192	5.980	1.788
Diet 3:					
CS-SPC	36.1	4.465	3.879	4.110	0.231
CS-SPC	38.1	4.522	4.579	5.180	0.601
CS-SPC	32.7	4.357	4.657	5.720	1.063
CS-SPC	39.5	4.557	3.764	4.750	0.986
CS-SPC	34.5	4.417	3.177	4.330	1.153
CS-SPC	34.0	4.402	4.167	4.270	0.103
Diet 4:					
CS-SPI	36.3	4.472	3.279	4.330	1.051
CS-SPI	30.6	4.282	3.012	3.000	-0.012
CS-SPI	31.3	4.308	3.680	4.350	0.670
CS-SPI	42.2	4.620	3.513	4.160	0.647
CS-SPI	38.1	4.522	4.317	5.530	1.213
CS-SPI	38.1	4.522	3.638	5.510	1.872

Table A-26. *(continue)*

	INIBW[a]	Simulation PHR(1)	PHR(2)[b]	Experiment	Difference[c]
Experiment 5					
Diet 1:					
CS-Caesin	23.7	4.051	4.834	2.588	-2.246
CS-Caesin	20.9	3.906	4.776	1.923	-2.853
CS-Caesin	24.1	4.072	4.014	1.926	-2.088
CS-Caesin	20.9	3.903	4.987	2.616	-2.372
CS-Caesin	20.7	3.895	4.400	1.733	-2.667
CS-Caesin	16.2	3.603	4.524	2.004	-2.520
Diet 2:					
Corn-SBM	14.9	3.498	4.135	3.969	-0.166
Corn-SBM	21.8	3.956	4.706	4.745	0.039
Corn-SBM	22.4	3.987	4.179	4.484	0.306
Corn-SBM	26.5	4.178	4.426	5.126	0.700
Corn-SBM	26.7	4.185	4.675	5.751	1.076
Corn-SBM	24.7	4.098	4.421	5.532	1.111
Diet 3:					
LPAA	26.5	4.178	4.463	5.370	0.907
LPAA	24.3	4.081	4.645	4.053	-0.592
LPAA	22.8	4.008	4.205	4.318	0.113
LPAA	22.0	3.963	4.344	5.077	0.733
LPAA	22.6	3.998	4.698	5.583	0.886
LPAA	20.0	3.850	3.255	2.915	-0.340
Diet 4:					
Corn-SPC	27.5	4.218	3.664	4.773	1.109
Corn-SPC	22.9	4.012	4.249	6.103	1.854
Corn-SPC	24.3	4.079	4.969	7.163	2.194
Corn-SPC	22.9	4.015	4.232	4.764	0.532
Corn-SPC	22.3	3.982	4.713	7.125	2.412
Corn-SPC	24.0	4.066	4.590	7.182	2.592

[a] INIBW is the initial body weight in kg.
[b] PHR(1) is the average daily phosphorus retention in grams per day calculated by the simulated digestible energy intake. PHR(2) is the average daily phosphorus retention in grams per day calculated by the experimental digestible energy intake.
[c] Difference is the difference in average daily phosphorus retention in grams per day between experimental and simulation value calculated by the simulated digestible energy intake.

Table A- 27. Difference Between the Results of Experiments and the Simulation Model.

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)	DFFI[a]	DFG:F[a]
Experiment 1							
Diet 1:							
CS&Caesin	29.62	-326.80	-7.90	-1.71	5.19	-519.86	-0.02
CS&Caesin	26.31	-126.38	10.98	2.46	5.32	-263.08	0.02
CS&Caesin	35.15	-359.25	-6.11	-1.01	6.44	-590.35	-0.02
CS&Caesin	27.03	-121.19	-61.52	4.73	5.80	-161.26	-0.02
CS&Caesin	33.57	-138.76	50.96	3.93	7.82	-347.69	0.04
CS&Caesin	28.35	-224.43	-263.18	7.17	5.94	-35.17	-0.13
Diet 2:							
Corn+CS&Caesin	33.02	-68.43	-0.82	9.14	10.29	-187.51	0.02
Corn+CS&Caesin	28.49	36.33	41.94	10.41	10.23	-90.29	0.05
Corn+CS&Caesin	31.25	-233.47	-50.79	4.89	8.68	-343.00	-0.03
Corn+CS&Caesin	21.18	167.23	-42.53	13.55	8.39	205.76	0.03
Corn+CS&Caesin	30.35	-29.96	38.26	8.63	9.82	-188.42	0.05
Diet 3:							
CS&Caesin+SBM	30.62	-170.07	-18.05	10.35	13.44	-295.99	0.00
CS&Caesin+SBM	26.72	120.37	125.09	14.24	14.06	-85.40	0.12
CS&Caesin+SBM	31.84	-423.99	61.96	2.33	12.94	-753.95	0.00
CS&Caesin+SBM	30.57	-178.39	15.53	7.80	11.86	-346.45	0.01
CS&Caesin+SBM	31.89	47.37	116.80	14.97	16.18	-182.44	0.10
Diet 4:							
Corn&SBM	31.66	-12.39	51.07	11.90	12.99	-179.30	0.05
Corn&SBM	22.14	300.40	281.74	9.98	9.31	-51.18	0.24
Corn&SBM	26.13	-14.12	199.99	8.09	12.74	-374.92	0.16
Corn&SBM	26.63	-531.03	-598.03	13.77	11.95	15.39	-0.33
Corn&SBM	30.62	-124.07	38.31	7.57	10.90	-322.01	0.04
Corn&SBM	32.61	-25.82	21.73	16.94	17.65	-158.59	0.04

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)	DFFI[a]	DFG:F[a]
Experiment 2							
Diet 1:							
CS&SBM	45.35	-77.52	81.48	3.53	6.56	-333.99	0.05
CS&SBM	31.75	-2.61	175.14	-0.30	3.38	-337.26	0.12
CS&SBM	44.44	-183.74	-19.47	2.45	5.59	-344.27	0.00
CS&SBM	34.01	-71.67	88.54	1.74	4.97	-319.05	0.06
CS&SBM	41.27	299.71	356.74	4.12	5.03	-165.93	0.20
CS&SBM	30.16	-168.12	-4.33	0.14	3.52	-319.52	0.00
Diet 2:							
CS&SBMH	43.76	-25.73	281.94	-0.96	5.32	-546.88	0.16
CS&SBMH	30.84	161.63	94.44	4.15	2.34	19.30	0.08
CS&SBMH	37.19	-34.71	31.75	-0.55	0.55	-185.58	0.04
CS&SBMH	39.00	-92.93	34.78	1.21	3.63	-278.46	0.03
CS&SBMH	42.18	214.93	220.47	3.28	3.05	-92.65	0.13
CS&SBMH	33.56	48.32	157.25	-0.46	1.65	-238.52	0.11
Diet 3:							
CS&SPC	32.65	-90.37	-144.41	3.87	2.31	-10.30	-0.05
CS&SPC	36.05	54.68	245.66	-0.02	3.87	-357.04	0.16
CS&SPC	38.10	295.00	300.83	4.38	4.18	-86.47	0.18
CS&SPC	39.46	-248.77	6.49	-1.57	3.63	-465.14	0.00
CS&SPC	34.01	-108.67	-15.29	-1.36	0.37	-220.50	0.01
CS&SPC	34.47	-228.55	145.29	-4.57	3.41	-621.90	0.09
Diet 4:							
CS&SPI	36.28	-62.05	301.06	-3.46	4.22	-606.92	0.20
CS&SPI	30.61	52.01	423.76	-4.49	3.60	-598.98	0.34
CS&SPI	31.29	-71.05	128.38	0.62	4.79	-363.48	0.09
CS&SPI	42.18	-200.07	149.08	-1.52	5.67	-604.91	0.08
CS&SPI	38.10	31.00	114.66	6.58	8.06	-207.51	0.08
CS&SPI	38.10	-196.00	83.27	0.28	6.04	-495.51	0.05

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 3							
Diet 1:							
Corn&SBM	34.06	190.08	213.68	9.87	10.11	-114.00	0.13
Corn&SBM	37.41	-272.54	-106.76	9.71	12.99	-360.29	-0.05
Corn&SBM	41.54	-89.19	20.48	10.74	12.76	-270.04	0.02
Corn&SBM	42.27	-122.11	-28.80	15.92	17.57	-246.25	0.00
Corn&SBM	44.13	-184.53	-53.51	10.57	13.02	-310.81	-0.02
Corn&SBM	44.22	9.25	141.94	4.97	7.47	-305.59	0.08
Diet 2:							
LPAA	31.97	516.84	445.28	8.99	7.17	50.36	0.25
LPAA	37.82	-93.42	-33.83	4.73	5.67	-192.68	0.00
LPAA	38.82	-177.95	-128.94	7.34	8.05	-174.82	-0.05
LPAA	40.68	-197.38	10.48	4.28	8.44	-427.62	0.01
LPAA	41.81	-266.94	49.16	-1.68	4.81	-603.22	0.02
LPAA	42.31	480.63	488.58	8.20	8.10	-84.40	0.24
Diet 3:							
Corn&SBMH	36.78	-116.02	73.18	5.31	9.15	-402.27	0.04
Corn&SBMH	37.14	-120.24	29.20	6.88	9.82	-338.94	0.02
Corn&SBMH	37.28	98.70	300.00	7.49	11.60	-413.64	0.17
Corn&SBMH	37.51	-72.52	5.87	10.14	11.52	-222.51	0.02
Corn&SBMH	43.85	64.35	257.32	6.25	10.06	-412.72	0.13
Corn&SBMH	44.31	-112.62	156.23	9.03	14.44	-551.92	0.08
Diet 4:							
Corn&SBMP	34.97	-87.47	203.47	0.74	6.87	-559.21	0.12
Corn&SBMP	37.37	259.80	338.04	10.89	12.31	-206.76	0.18
Corn&SBMP	40.00	36.57	194.54	3.44	6.55	-349.79	0.10
Corn&SBMP	41.50	99.34	266.81	9.12	12.42	-364.89	0.14
Corn&SBMP	41.86	-127.93	-50.10	12.54	13.84	-234.60	-0.01
Corn&SBMP	42.68	-145.40	46.84	8.43	12.22	-417.56	0.03

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 4							
Diet 1:							
Corn&SBM	38.23	-160.70	291.98	-3.62	5.88	-858.17	0.18
Corn&SBM	33.06	-69.11	219.78	-1.25	4.95	-568.72	0.14
Corn&SBM	37.60	-255.74	194.13	-3.65	5.83	-852.72	0.11
Corn&SBM	32.88	-46.92	275.99	-0.72	6.25	-620.82	0.18
Corn&SBM	32.15	-270.70	49.31	-1.81	5.14	-618.31	0.02
Corn&SBM	28.25	-91.78	223.69	-2.21	4.93	-583.77	0.15
Diet 2:							
LPAA	38.10	62.22	355.32	-2.71	3.29	-602.72	0.21
LPAA	28.12	-160.57	108.28	-2.68	3.40	-518.70	0.07
LPAA	36.73	-227.60	62.17	-0.45	5.53	-599.01	0.03
LPAA	34.24	-1.13	216.76	0.38	4.92	-465.74	0.13
LPAA	31.66	-244.78	71.57	-2.32	4.57	-616.32	0.04
LPAA	31.52	-122.31	54.93	-2.10	1.67	-391.57	0.04
Diet 3:							
Corn&SPC	32.06	-148.67	233.85	-5.59	2.78	-707.21	0.15
Corn&SPC	37.14	-291.84	10.74	-4.60	1.64	-611.31	0.00
Corn&SPC	33.61	-337.11	-44.93	-2.53	3.69	-579.40	-0.03
Corn&SPC	31.97	-107.33	231.41	-4.78	2.61	-637.41	0.15
Corn&SPC	26.94	-336.02	-4.43	-5.43	2.17	-602.19	-0.02
Corn&SPC	31.52	-11.41	158.51	-1.80	1.81	-369.49	0.10
Diet 4:							
Corn&SPI	37.41	-143.17	372.32	-7.63	3.32	-955.96	0.24
Corn&SPI	29.39	-207.24	39.85	-2.33	3.16	-488.53	0.03
Corn&SPI	32.20	-140.11	163.19	-2.61	3.96	-590.06	0.10
Corn&SPI	34.78	-208.36	139.06	-3.79	3.59	-675.24	0.08
Corn&SPI	32.79	4.49	302.18	-3.11	3.31	-580.44	0.19
Corn&SPI	26.30	-196.06	37.71	-3.79	1.61	-449.60	0.02

Table A-27 *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 5							
Diet 1:							
CS&Caesin	23.67	-199.31	-332.20	4.04	1.16	124.98	-0.15
CS&Caesin	20.73	-414.16	-457.22	1.28	0.63	1.88	-0.28
CS&Caesin	16.24	-174.63	-293.41	1.95	-0.15	141.72	-0.18
CS&Caesin	20.91	-183.00	-322.22	3.62	0.74	146.33	-0.16
CS&Caesin	24.13	-206.44	-127.99	-0.57	1.42	-180.06	-0.07
CS&Caesin	20.86	-280.49	-468.56	2.54	-1.51	211.40	-0.23
Diet 2:							
Corn&SBM	26.49	-60.14	-70.23	6.87	6.69	-61.75	-0.02
Corn&SBM	26.67	-130.71	-203.21	2.63	1.00	31.23	-0.08
Corn&SBM	24.67	-154.34	-175.69	13.49	13.14	-39.96	-0.08
Corn&SBM	22.40	32.99	49.11	6.39	7.07	-77.85	0.05
Corn&SBM	21.81	73.17	-66.91	12.75	9.96	198.33	-0.02
Corn&SBM	14.88	-114.23	-161.06	17.21	16.95	56.89	-0.11
Diet 3:							
LPAA	26.49	189.36	164.94	-1.63	-2.10	-29.55	0.11
LPAA	24.31	-209.26	-289.34	4.58	2.89	50.35	-0.13
LPAA	22.63	-280.68	-384.91	2.72	0.55	92.40	-0.18
LPAA	22.81	-11.58	2.65	-1.13	-0.52	-80.36	0.02
LPAA	21.95	-133.15	-158.80	2.81	2.53	-19.12	-0.07
LPAA	19.95	-324.54	-102.41	0.12	5.79	-394.85	-0.10
Diet 4:							
Corn&SPC	22.90	-43.27	-38.58	6.25	6.63	-66.12	-0.01
Corn&SPC	27.48	-263.02	-62.22	5.25	9.83	-401.06	-0.04
Corn&SPC	24.26	10.64	-157.63	6.39	2.70	194.39	-0.05
Corn&SPC	22.95	-44.01	-34.68	1.54	2.02	-73.47	0.00
Corn&SPC	22.31	34.51	-84.09	4.71	2.27	127.90	-0.02
Corn&SPC	23.99	-416.02	-479.71	-5.04	-6.37	16.84	-0.24

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 6							
Diet 1:							
CornA	24.63	-157.12	100.35	-3.14	2.63	-449.43	0.07
CornA	28.80	-32.41	118.41	-1.34	1.87	-296.85	0.08
CornA	31.43	-573.80	-89.12	-8.31	2.36	-827.54	-0.14
CornA	35.83	256.25	457.81	-2.23	1.99	-381.00	0.27
CornA	32.93	40.64	175.90	-1.19	1.59	-278.77	0.11
CornA	30.43	-304.06	3.69	-5.59	1.13	-546.99	-0.02
Diet 2:							
CornB	34.56	-136.27	-3.77	-2.12	0.55	-265.66	0.00
CornB	30.11	-108.22	201.10	-6.19	0.58	-509.41	0.14
CornB	26.62	-231.02	-69.83	-2.27	1.21	-294.32	-0.05
CornB	20.73	-392.51	-100.51	-5.96	0.75	-463.21	-0.15
CornB	33.15	-380.65	-1.00	-6.97	1.27	-626.69	-0.04
CornB	30.25	-1.29	182.02	-4.08	-0.17	-327.16	0.13
Diet 3:							
CornC	36.78	180.77	386.24	-1.56	2.72	-387.13	0.23
CornC	19.18	-156.00	24.23	-1.80	2.33	-314.26	0.02
CornC	26.17	-95.50	65.03	-1.09	2.39	-304.80	0.05
CornC	31.16	-133.42	195.85	-3.95	3.24	-569.89	0.13
CornC	35.28	54.17	272.76	-0.78	3.81	-407.59	0.17
CornC	28.84	-133.14	131.52	-3.09	2.70	-466.98	0.09
Diet 4:							
CornD	27.80	-406.36	-168.58	-2.99	2.20	-430.93	-0.14
CornD	28.57	-428.55	170.40	-12.16	1.28	-970.88	0.11
CornD	21.54	-401.85	-20.76	-8.07	0.70	-618.50	-0.08
CornD	33.11	-25.54	386.22	-6.65	2.33	-697.45	0.28
CornD	37.96	66.68	190.18	1.08	3.52	-264.35	0.11
CornD	30.20	-245.98	91.06	-4.67	2.72	-581.28	0.05

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 7							
Diet 1:							
CornHA	23.58	-363.49	20.75	-8.53	0.22	-652.58	-0.03
CornHA	24.04	-736.23	-409.74	-6.26	1.11	-578.35	-0.43
CornHA	27.66	-258.58	99.27	-4.87	3.09	-625.83	0.05
CornHA	29.48	-652.52	-335.13	-5.47	1.48	-581.38	-0.29
CornHA	31.29	-680.82	-352.36	-4.56	2.57	-604.97	-0.29
CornHA	35.37	-374.19	12.55	-5.93	2.39	-699.57	-0.02
CornHA	32.43	-561.20	-54.98	-9.13	1.99	-880.86	-0.11
Diet 2:							
CornHB	32.88	-295.01	224.04	-10.36	1.04	-885.11	0.14
CornHB	22.68	-435.52	-116.49	-6.72	0.54	-545.80	-0.15
CornHB	28.34	-497.45	-170.37	-5.29	1.92	-579.72	-0.17
CornHB	27.44	-754.53	-348.15	-7.88	1.19	-703.90	-0.38
CornHB	31.07	-768.28	-397.08	-7.65	0.46	-678.66	-0.35
CornHB	31.97	-372.82	20.90	-6.48	2.12	-690.16	-0.02
CornHB	28.12	-629.94	-295.40	-8.90	-1.51	-594.10	-0.28
CornHB	24.94	-572.30	-244.15	-6.43	0.95	-571.77	-0.26
Diet 3:							
CornHC	29.48	-743.41	-331.89	-8.75	0.35	-733.21	-0.34
CornHC	22.68	-435.52	-183.30	-6.92	-1.22	-455.93	-0.18
CornHC	23.58	-454.38	-205.26	-4.36	1.23	-454.93	-0.19
CornHC	29.48	-470.74	-218.33	-6.25	-0.78	-478.71	-0.17
CornHC	29.02	-826.91	-338.29	-9.51	1.37	-852.84	-0.41
CornHC	36.73	-754.85	-295.78	-8.00	1.86	-841.35	-0.27
CornHC	32.20	-512.47	-178.80	-6.37	0.86	-614.60	-0.16
CornHC	29.48	-561.63	-233.06	-5.07	2.14	-599.53	-0.21

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 8							
Diet 1:							
Corn&Caesin	22.09	-406.29	-152.78	-3.98	1.84	-416.97	-0.19
Corn&Caesin	23.81	-216.10	-75.90	-0.32	2.82	-249.29	-0.07
Corn&Caesin	18.55	-241.70	15.70	-5.28	0.76	-407.69	-0.02
Corn&Caesin	26.49	-322.83	-126.82	-1.30	3.07	-340.54	-0.11
Corn&Caesin	27.26	-300.69	-75.92	-1.76	3.25	-384.43	-0.08
Corn&Caesin	32.29	-456.39	-275.79	-1.03	2.85	-332.36	-0.19
Corn&Caesin	34.24	-330.55	-313.28	7.07	7.26	-81.57	-0.16
Corn&Caesin	27.94	-95.14	-59.50	4.29	4.97	-96.33	-0.03
Corn&Caesin	29.48	-293.91	-143.23	0.79	4.05	-277.51	-0.10
Corn&Caesin	31.88	-305.07	-109.95	-0.03	4.20	-349.25	-0.09
Corn&Caesin	33.02	-376.47	-142.12	1.42	6.51	-413.16	-0.11
Diet 2:							
RS&Caesin	27.76	-182.64	27.85	2.71	7.39	-386.85	0.01
RS&Caesin	27.57	-206.62	-103.44	3.93	6.15	-215.02	-0.07
RS&Caesin	27.66	-616.40	-218.21	-5.16	3.82	-700.39	-0.26
RS&Caesin	22.00	-23.35	35.52	5.92	7.21	-129.52	0.03
RS&Caesin	25.62	-215.85	-75.27	3.16	6.28	-271.59	-0.06
RS&Caesin	28.12	-306.95	-188.64	6.02	8.57	-243.51	-0.12
RS&Caesin	35.83	-188.95	-66.57	7.07	9.61	-257.72	-0.04
RS&Caesin	26.67	-172.00	32.66	1.03	5.60	-374.66	0.01
RS&Caesin	18.32	-208.78	-2.70	-2.17	2.65	-356.37	-0.03
RS&Caesin	35.60	-285.70	-51.93	2.85	7.87	-444.54	-0.05
RS&Caesin	23.54	-482.59	-70.72	-5.24	4.24	-702.92	-0.15
RS&Caesin	38.46	-358.33	-82.85	3.57	9.45	-521.57	-0.07
Diet 3:							
WS&Caesin	24.13	-258.86	31.16	-1.46	5.16	-498.34	-0.01
WS&Caesin	18.55	-277.98	-30.59	-2.14	3.66	-416.26	-0.07
WS&Caesin	22.49	-179.34	-27.38	2.65	6.10	-277.43	-0.03
WS&Caesin	29.16	-125.33	205.34	-2.33	5.06	-573.24	0.13
WS&Caesin	23.58	-265.85	-94.17	0.98	4.86	-313.14	-0.09
WS&Caesin	31.25	-141.06	63.98	0.91	5.39	-378.25	0.03
WS&Caesin	27.26	-110.21	11.73	4.82	7.49	-255.47	0.01
WS&Caesin	31.75	-348.34	-72.15	0.39	6.45	-499.67	-0.07
WS&Caesin	30.07	-258.28	-187.06	4.81	6.26	-166.20	-0.11
WS&Caesin	30.25	-134.25	-114.86	5.36	5.65	-79.57	-0.05
WS&Caesin	29.84	-136.66	264.48	-3.54	5.43	-687.86	0.18
WS&Caesin	29.39	-201.70	-7.03	2.54	6.82	-359.80	-0.02

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 9-1[b]							
Diet 1:							
Corn&SBM	37.64	-131.19	123.73	1.23	6.81	-413.40	0.05
Corn&SBM	33.56	15.51	283.07	3.03	8.99	-419.30	0.16
Corn&SBM	32.65	-106.99	175.20	-0.03	6.26	-447.82	0.09
Corn&SBM	28.12	12.84	245.31	0.41	5.69	-356.49	0.15
Corn&SBM	23.58	281.53	315.70	6.24	7.08	-31.73	0.21
Diet 2:							
CS1+Corn&SBM	36.73	-74.06	98.31	1.12	4.91	-261.67	0.04
CS1+Corn&SBM	29.48	-56.10	42.24	2.97	5.18	-145.30	0.02
CS1+Corn&SBM	33.56	-211.24	59.78	-4.71	1.30	-412.89	0.01
CS1+Corn&SBM	24.94	117.81	76.99	9.52	8.61	68.42	0.05
CS1+Corn&SBM	30.39	19.49	225.50	0.85	5.49	-300.08	0.14
Diet 3:							
CS2+Corn&SBM	38.10	-273.00	-139.77	5.50	8.37	-210.84	-0.10
CS2+Corn&SBM	32.20	-9.36	109.33	1.89	4.55	-171.00	0.06
CS2+Corn&SBM	36.28	-68.03	199.28	-1.35	4.54	-395.90	0.10
CS2+Corn&SBM	28.57	95.56	255.73	1.83	5.48	-222.30	0.17
CS2+Corn&SBM	24.49	126.89	18.93	11.05	8.60	162.52	0.02
Diet 4:							
Corn&SBM+Hl	38.55	-97.26	199.98	0.74	7.24	-481.39	0.09
Corn&SBM+Hl	35.83	-243.32	90.56	-0.45	6.90	-543.39	0.02
Corn&SBM+Hl	31.75	-2.32	269.64	-4.76	1.34	-425.12	0.16
Corn&SBM+Hl	26.76	37.58	232.89	-0.94	3.52	-296.38	0.15
Corn&SBM+Hl	22.22	-52.24	-88.44	-0.49	-1.33	53.84	-0.06

Table A-27. *(continue)*

	INIBW[a]	DFADG(1)[a]	DFADG(2)[a]	DFNR(1)[a]	DFNR(2)[a]	DFADFI[a]	DFG:F[a]
Experiment 9-2[c]							
Diet 1:							
Corn&SBM	43.08	-349.59	66.46	-2.15	6.09	-867.69	0.03
Corn&SBM	36.73	-145.04	184.23	3.84	10.42	-696.71	0.11
Corn&SBM	46.26	-182.15	255.78	-0.77	7.89	-900.19	0.13
Corn&SBM	40.82	-143.28	92.01	3.79	8.22	-555.02	0.06
Corn&SBM	34.01	-79.22	237.93	-0.44	5.96	-664.34	0.15
Diet 2:							
CS1+Corn&SBM	45.80	-254.84	55.41	4.95	10.88	-654.98	0.03
CS1+Corn&SBM	37.64	-153.63	55.30	4.02	7.93	-478.11	0.05
CS1+Corn&SBM	40.82	-256.66	-92.14	1.59	4.46	-423.21	-0.02
CS1+Corn&SBM	39.46	-358.76	-113.85	0.43	5.04	-550.28	-0.05
CS1+Corn&SBM	34.01	-192.60	-50.07	0.81	3.32	-373.19	0.00
Diet 3:							
CS2+Corn&SBM	45.35	-62.93	114.27	3.44	6.58	-427.25	0.07
CS2+Corn&SBM	41.27	-373.65	-142.76	-1.56	2.71	-523.12	-0.06
CS2+Corn&SBM	45.35	-176.31	29.20	3.24	6.96	-477.69	0.03
CS2+Corn&SBM	33.56	-111.99	71.21	1.84	5.28	-419.14	0.06
CS2+Corn&SBM	38.10	-195.59	-44.89	0.88	3.51	-386.17	0.00
Diet 4:							
Corn&SBM+Hl	47.62	-266.08	98.62	5.63	12.69	-789.04	0.05
Corn&SBM+Hl	43.08	-236.21	92.57	0.28	6.66	-719.27	0.05
Corn&SBM+Hl	40.82	-67.69	116.45	3.97	7.31	-467.43	0.07
Corn&SBM+Hl	35.37	-169.26	147.35	-0.69	5.64	-675.29	0.09
Corn&SBM+Hl	29.02	-206.51	62.12	2.14	7.60	-580.38	0.05

[a] INIBW is the initial body weight in kg. DFADG(1) is the difference in average daily body weight gains in grams per day between experimental and simulation value calculated by the simulated digestible energy intake. DFADG(2) is the difference in average daily body weight gains in grams per day between experimental and simulation value calculated by the experimental digestible energy intake. DFNR(1) is the difference between experimental and simulation value for average daily nitrogen retention in grams per day, calculated by the simulated digestible energy intake. DFNR(2) is the difference in average daily nitrogen retention in grams per day between experimental and simulation value calculated by the experimental digestible energy intake. DFADFI is the difference between experimental and simulation value for average daily feed intake in grams per day. DFG:F (ADG/ADFI) is the difference between experimental and simulated efficiency of feed utilization, in which the simulated daily body weight gain was calculated by the experimental DE intake.

[b]Data concerning Experiment 9-1 corresponds to the first collection period of the experiment 9.

[c]Data concerning Experiment 9-2 corresponds to the second collection period of the experiment 9.

Table A- 28. The Average Experimental and Estimated Values of N Intake, Retention, and Excretion for Different Diet.

Experiment 1		Experiment			Simulation				
	Wt[a]	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
Diets									
CS&Casein	29.6	22.7	21.0	1.7	18.8	19.1	4.3	0.4	-2.6
CS&Casein	26.3	25.4	24.1	1.3	21.1	22.5	3.8	0	-2.4
CS&Casein	35.2	24.9	23.1	1.8	20.6	20.3	5.3	1.0	-3.5
CS&Casein	27.0	28.0	26.6	1.4	23.2	25.0	3.9	0	-2.5
CS&Casein	33.6	28.8	27.7	1.1	23.8	24.3	5.4	0.5	-4.4
CS&Casein	28.3	31.5	29.5	2.0	26.1	28.4	4.2	0	-2.2
Corn+CS-Casein	33.0	40.2	32.8	7.4	37.0	29.9	11.4	8.3	-4.0
Corn+CS-Casein	28.5	38.7	32.8	5.9	35.6	29.7	10.1	7.1	-4.2
Corn+CS-Casein	31.3	34.9	28.1	6.9	32.2	25.7	10.2	7.4	-3.3
Corn+CS-Casein	21.2	38.6	33.1	5.5	35.6	31.9	7.9	4.8	-2.4
Corn+CS-Casein	30.3	38.0	31.5	6.4	34.9	28.7	10.3	7.3	-3.9
CS&Casein+SBM	30.6	41.3	33.3	7.9	32.6	27.2	15.1	6.4	-7.1
CS&Casein+SBM	26.7	43.4	36.0	7.4	34.2	29.8	14.7	5.5	-7.3
CS&Casein+SBM	31.8	29.0	25.7	3.4	22.9	17.5	12.2	6.1	-8.9
CS&Casein+SBM	30.6	39.8	30.8	9.0	31.4	25.9	14.8	6.4	-5.8
CS&Casein+SBM	31.9	45.9	38.3	7.6	36.2	30.4	16.6	7.0	-9.1
Corn-SBM	31.7	50.8	35.2	15.6	47.2	31.0	21.0	17.4	-5.4
Corn-SBM	22.1	43.1	30.0	13.2	40.1	28.2	16.0	13.0	-2.8
Corn-SBM	26.1	38.3	29.7	8.6	35.6	23.3	15.8	13.1	-7.2
Corn-SBM	26.6	51.1	35.5	15.6	47.5	32.5	19.8	16.2	-4.2
Corn-SBM	30.6	45.2	30.6	14.6	42.0	27.4	18.9	15.7	-4.2
Corn-SBM	32.6	52.4	40.5	12.0	48.8	31.9	21.7	18.1	-9.8
Mean	29.4	37.8	30.7	7.1	33.1	26.8	12.0	7.2	-4.9

Table A-28. *(continue)*

Experiment 2		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
CS&SBM	45.4	42.3	29.4	12.9	42.0	29.4	14.0	13.7	-1.1
CS&SBM	31.7	33.3	23.0	10.3	33.0	24.6	9.7	9.4	0.6
CS&SBM	44.4	41.6	28.2	13.4	41.3	29.0	13.7	13.4	-0.3
CS&SBM	34.0	35.4	25.6	9.8	35.2	26.0	10.5	10.2	-0.6
CS&SBM	41.3	43.8	29.4	14.4	43.4	31.2	13.8	13.4	0.6
CS&SBM	30.2	32.5	23.0	9.5	32.2	24.3	9.1	8.8	0.4
CS&SBMH	43.8	35.3	24.7	10.6	36.3	24.6	11.6	12.6	-1.0
CS&SBMH	30.8	39.2	27.2	12.0	40.3	30.8	9.6	10.7	2.4
CS&SBMH	37.2	39.2	24.0	15.2	40.3	29.4	10.9	12.0	4.3
CS&SBMH	39.0	38.4	26.1	12.3	39.4	28.3	11.2	12.2	1.1
CS&SBMH	42.2	44.4	28.7	15.7	45.6	32.6	13.1	14.3	2.6
CS&SBMH	33.6	35.6	23.3	12.3	36.6	27.0	9.6	10.6	2.7
CS&SPC	32.7	38.1	27.4	10.7	35.5	30.8	8.5	5.8	2.3
CS&SPC	36.1	33.1	24.3	8.8	30.8	25.3	8.8	6.4	0.1
CS&SPC	38.1	40.1	29.1	11.0	37.3	31.0	10.3	7.4	0.8
CS&SPC	39.5	32.9	23.4	9.5	30.6	24.6	9.3	6.9	0.3
CS&SPC	34.0	34.7	22.5	12.2	32.2	27.3	8.4	6.0	3.7
CS&SPC	34.5	26.5	19.4	7.1	24.6	19.7	7.5	5.6	-0.4
CS&SPI	36.3	30.2	20.9	9.3	29.5	21.2	9.7	9.1	-0.5
CS&SPI	30.6	26.2	18.5	7.7	25.6	18.8	8.1	7.5	-0.4
CS&SPI	31.3	32.1	23.8	8.3	31.4	23.9	9.1	8.3	-0.8
CS&SPI	42.2	34.0	23.9	10.1	33.3	23.5	11.4	10.7	-1.3
CS&SPI	38.1	40.6	31.3	9.3	39.6	29.7	12.0	11.0	-2.7
CS&SPI	38.1	34.0	25.0	9.0	33.2	24.2	10.7	9.9	-1.7
Mean	36.9	36.0	25.1	10.9	35.4	26.6	10.4	9.8	0.5

Table A-28. *(continue)*

Experiment 3		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
Corn-SBM	34.1	56.8	33.7	23.1	55.8	32.4	25.6	24.6	-2.5
Corn-SBM	37.4	52.8	34.3	18.5	51.9	29.4	24.6	23.6	-6.0
Corn-SBM	41.5	59.2	36.1	23.2	58.2	32.4	28.0	27.0	-4.9
Corn-SBM	42.3	60.6	41.4	19.2	59.5	33.1	28.7	27.6	-9.5
Corn-SBM	44.1	60.2	36.3	23.9	59.1	32.5	28.9	27.8	-5.0
Corn-SBM	44.2	60.4	30.7	29.7	59.3	32.5	29.2	28.1	0.6
LPAA	32.0	45.1	32.3	12.8	43.0	31.3	15.0	12.9	-2.2
LPAA	37.8	44.2	29.4	14.8	42.1	29.8	15.5	13.4	-0.8
LPAA	38.8	45.3	32.2	13.1	43.1	30.4	16.1	13.9	-3.0
LPAA	40.7	40.8	29.5	11.4	38.9	26.5	15.3	13.4	-3.9
LPAA	41.8	37.6	23.7	13.9	35.8	23.8	14.7	12.9	-0.7
LPAA	42.3	49.7	33.6	16.0	47.3	32.5	18.4	16.0	-2.4
Corn&SBMH	36.8	44.0	29.8	14.2	42.1	25.9	19.0	17.1	-4.8
Corn&SBMH	37.1	45.8	31.4	14.4	43.9	27.2	19.7	17.7	-5.3
Corn&SBMH	37.3	44.1	32.1	12.0	42.2	25.8	19.3	17.4	-7.2
Corn&SBMH	37.5	49.0	34.8	14.2	46.9	29.3	20.8	18.7	-6.6
Corn&SBMH	43.9	49.1	31.9	17.2	47.0	27.9	22.3	20.2	-5.1
Corn&SBMH	44.3	46.0	34.8	11.2	44.0	25.9	21.1	19.1	-9.8
Corn&SBMP	35.0	37.0	24.8	12.2	35.8	22.4	15.5	14.3	-3.3
Corn&SBMP	37.4	47.3	35.5	11.9	45.8	29.1	19.3	17.8	-7.4
Corn&SBMP	40.0	46.0	28.5	17.4	44.5	27.7	19.3	17.8	-1.8
Corn&SBMP	41.5	46.7	34.4	12.2	45.2	27.9	19.8	18.3	-7.6
Corn&SBMP	41.9	50.0	37.9	12.1	48.4	30.4	20.7	19.1	-8.6
Corn&SBMP	42.7	46.3	33.9	12.3	44.7	27.5	19.8	18.3	-7.4
Mean	39.7	48.5	32.6	15.9	46.9	28.9	20.7	19.0	-4.8

Table A-28. *(continue)*

Experiment 4		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
Corn-SBM	38.2	38.9	21.3	17.6	43.4	21.6	18.1	22.5	-0.5
Corn-SBM	33.1	42.2	23.0	19.2	47.1	25.0	18.1	23.0	1.1
Corn-SBM	37.6	38.5	21.2	17.3	42.9	21.5	17.8	22.2	-0.5
Corn-SBM	32.9	40.5	23.5	17.0	45.3	23.9	17.5	22.3	-0.5
Corn-SBM	32.2	40.0	22.3	17.7	44.6	23.7	17.2	21.7	0.5
Corn-SBM	28.3	36.9	21.2	15.7	41.1	22.3	15.4	19.7	0.3
LPAA	38.1	36.4	22.2	14.2	41.1	24.7	12.6	17.3	1.6
LPAA	28.1	30.6	20.7	9.9	34.5	22.1	9.3	13.3	0.6
LPAA	36.7	35.4	24.3	11.1	40.1	24.4	11.9	16.6	-0.8
LPAA	34.2	36.6	24.8	11.8	41.3	25.8	11.8	16.5	0.0
LPAA	31.7	31.2	21.7	9.5	35.4	22.0	10.0	14.2	-0.5
LPAA	31.5	36.2	21.9	14.3	40.8	26.1	11.1	15.7	3.2
Corn&SPC	32.1	28.3	18.5	9.8	32.2	20.3	8.7	12.7	1.1
Corn&SPC	37.1	34.0	20.2	13.8	38.6	24.2	10.7	15.3	3.1
Corn&SPC	33.6	32.3	21.8	10.5	36.6	23.5	9.7	14.0	0.8
Corn&SPC	32.0	29.8	19.3	10.5	33.9	21.6	9.0	13.1	1.5
Corn&SPC	26.9	26.4	17.7	8.7	30.1	19.8	7.3	11.0	1.4
Corn&SPC	31.5	35.1	22.2	12.9	39.9	26.3	9.8	14.6	3.1
Corn&SPI	37.4	27.8	17.2	10.6	31.3	18.1	10.4	13.9	0.2
Corn&SPI	29.4	31.8	21.3	10.5	36.0	23.2	9.4	13.6	1.1
Corn&SPI	32.2	31.9	21.5	10.4	36.0	22.6	10.1	14.2	0.3
Corn&SPI	34.8	32.0	20.7	11.3	36.1	22.2	10.7	14.8	0.6
Corn&SPI	32.8	32.6	21.1	11.5	36.7	23.0	10.5	14.6	1.0
Corn&SPI	26.3	30.1	19.2	10.9	33.9	22.4	8.6	12.4	2.3
Mean	32.9	34.0	21.2	12.8	38.3	22.9	11.9	16.2	0.9

Table A-28. *(continue)*

Experiment 5		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
CS&Casein	23.7	28.6	26.4	2.2	31.2	33.5	-3.6	-1.0	5.8
CS&Casein	20.7	24.5	22.8	1.7	26.8	29.2	-3.6	-1.3	5.3
CS&Casein	16.2	23.3	21.9	1.4	25.5	28.7	-4.4	-2.2	5.8
CS&Casein	20.9	27.0	25.2	1.8	29.5	32.3	-4.0	-1.5	5.8
CS&Casein	24.1	23.9	21.9	2.0	26.1	27.2	-2.3	-0.1	4.3
CS&Casein	20.9	28.1	24.1	4.0	30.6	33.7	-4.4	-1.8	8.4
Corn-SBM	26.5	45.4	29.9	15.5	56.7	30.4	16.1	27.4	-0.6
Corn-SBM	26.7	41.5	25.7	15.8	59.9	32.4	10.3	28.7	5.5
Corn-SBM	24.7	54.4	36.1	18.3	55.0	29.9	25.6	26.2	-7.3
Corn-SBM	22.4	45.3	28.4	16.9	50.6	27.7	18.6	23.9	-1.7
Corn-SBM	21.8	50.0	34.6	15.4	58.5	32.1	19.1	27.6	-3.7
Corn-SBM	14.9	49.0	36.6	12.4	42.8	25.0	24.9	18.7	-12.5
LPAA	26.5	37.2	21.4	15.8	46.8	30.2	8.1	17.7	7.7
LPAA	24.3	39.3	27.1	12.2	46.5	30.9	9.6	16.7	2.6
LPAA	22.6	36.1	24.8	11.3	45.6	30.8	6.5	16.0	4.8
LPAA	22.8	33.3	21.0	12.3	41.5	27.4	6.9	15.1	5.4
LPAA	22.0	38.4	24.7	13.7	42.0	28.1	11.3	14.9	2.4
LPAA	20.0	28.0	21.4	6.6	30.1	19.7	9.1	11.1	-2.5
Corn&SPC	22.9	40.4	28.4	12.0	40.9	23.5	17.8	18.3	-5.8
Corn&SPC	27.5	40.1	28.5	11.6	37.4	20.4	20.5	17.8	-8.9
Corn&SPC	24.3	39.4	28.9	10.5	49.0	28.4	12.0	21.6	-1.5
Corn&SPC	22.9	35.8	23.7	12.1	40.8	23.4	13.2	18.2	-1.1
Corn&SPC	22.3	36.3	26.7	9.6	45.1	26.4	10.9	19.7	-1.3
Corn&SPC	24.0	25.9	17.4	8.5	44.2	25.7	1.2	19.5	7.3
Mean	22.7	36.3	26.2	10.2	41.8	28.2	9.1	14.6	1.0

Table A-28. *(continue)*

Experiment 6		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
CornA	24.6	22.8	17.3	5.5	24.1	16.7	6.7	8.0	-1.3
CornA	28.8	29.3	20.6	8.7	31.0	21.5	8.6	10.3	0.1
CornA	31.4	20.8	14.4	6.3	22.0	13.9	7.4	8.6	-1.1
CornA	35.8	32.8	21.6	11.2	34.7	22.9	10.7	12.6	0.4
CornA	32.9	32.8	22.0	10.8	34.7	23.6	10.1	11.9	0.8
CornA	30.4	25.6	16.9	8.7	27.1	18.1	8.2	9.6	0.6
CornB	34.6	32.4	21.5	11.0	33.6	24.7	8.6	9.8	2.3
CornB	30.1	24.4	16.2	8.2	25.3	18.3	6.8	7.7	1.4
CornB	26.6	26.0	18.9	7.1	27.0	20.6	6.2	7.1	0.9
CornB	20.7	17.5	12.8	4.7	18.1	13.8	4.2	4.9	0.5
CornB	33.2	24.1	16.3	7.9	25.0	17.7	7.2	8.0	0.7
CornB	30.2	28.2	18.3	9.8	29.2	21.7	7.3	8.3	2.6
CornC	36.8	34.5	22.5	12.0	34.5	24.1	11.4	11.3	0.7
CornC	19.2	21.0	16.1	4.8	20.9	16.1	5.5	5.5	-0.6
CornC	26.2	28.0	20.0	8.0	27.9	20.8	7.9	7.9	0.1
CornC	31.2	26.6	18.7	7.8	26.5	18.6	8.7	8.6	-0.8
CornC	35.3	33.1	23.0	10.1	33.0	23.2	10.7	10.7	-0.6
CornC	28.8	26.9	18.9	8.0	26.8	19.3	8.3	8.2	-0.3
CornD	27.8	26.5	18.6	7.9	26.8	19.4	7.8	8.1	0.0
CornD	28.6	15.9	9.7	6.2	16.1	10.0	6.3	6.5	-0.1
CornD	21.5	16.9	11.0	5.8	17.1	12.0	5.3	5.5	0.5
CornD	33.1	25.2	16.6	8.6	25.4	17.0	8.8	9.0	-0.2
CornD	38.0	37.6	25.4	12.2	38.0	26.5	12.1	12.5	0.1
CornD	30.2	25.3	17.7	7.6	25.6	17.8	8.2	8.5	-0.6
Mean	29.8	26.4	18.1	8.3	27.1	19.1	8.0	8.7	0.3

Table A-28. *(continue)*

Experiment 7		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
CornHA	23.6	18.8	11.5	7.3	19.4	13.0	6.3	6.9	1.0
CornHA	24.0	20.7	14.0	6.8	21.4	14.7	6.5	7.2	0.2
CornHA	27.7	23.0	16.7	6.3	23.7	15.8	7.8	8.5	-1.5
CornHA	29.5	25.4	16.7	8.7	26.2	17.7	8.4	9.2	0.3
CornHA	31.3	26.4	18.2	8.2	27.2	18.2	8.9	9.7	-0.7
CornHA	35.4	27.5	17.8	9.7	28.4	18.2	10.0	10.8	-0.3
CornHA	32.4	21.6	13.9	7.7	22.3	13.9	8.2	8.9	-0.5
CornHB	32.9	20.6	12.8	7.8	22.2	13.4	7.7	9.3	0.1
CornHB	22.7	18.9	12.9	6.0	20.4	13.7	5.7	7.2	0.3
CornHB	28.3	23.1	16.5	6.6	25.0	16.4	7.3	9.2	-0.7
CornHB	27.4	20.0	13.6	6.3	21.6	13.9	6.5	8.1	-0.2
CornHB	31.1	23.6	15.0	8.6	25.5	16.4	7.7	9.6	0.8
CornHB	32.0	23.7	16.4	7.3	25.6	16.2	8.1	10.0	-0.8
CornHB	28.1	22.7	12.8	9.8	24.5	16.1	7.1	8.9	2.7
CornHB	24.9	20.4	14.2	6.3	22.1	14.7	6.3	7.9	0.0
CornHC	29.5	22.0	13.4	8.6	23.4	14.9	7.6	9.0	0.9
CornHC	22.7	21.5	12.7	8.8	22.9	15.7	6.5	7.8	2.4
CornHC	23.6	22.4	15.7	6.8	23.8	16.3	6.8	8.2	0.0
CornHC	29.5	27.0	15.9	11.1	28.7	19.1	8.7	10.4	2.4
CornHC	29.0	19.3	12.5	6.7	20.5	12.7	7.0	8.2	-0.3
CornHC	36.7	25.3	16.1	9.3	26.9	16.5	9.5	11.1	-0.2
CornHC	32.2	26.5	16.6	9.9	28.1	18.1	9.1	10.7	0.8
CornHC	29.5	24.6	17.1	7.5	26.2	17.1	8.2	9.7	-0.7
Mean	28.9	22.8	14.9	7.9	24.2	15.8	7.6	9.0	0.3

Table A-28. *(continue)*

Experiment 8	Wt	Experiment NIT	NRet	NExc	Simulation NIT	NRet	NExc1	NExc2	DFNExc
Corn&Casein	22.1	20.9	14.6	6.2	21.8	15.2	6.3	7.1	0.0
Corn&Casein	23.8	26.2	19.1	7.1	27.3	19.4	7.5	8.6	-0.4
Corn&Casein	18.5	17.4	11.5	5.9	18.1	12.7	5.2	5.9	0.7
Corn&Casein	26.5	26.7	19.2	7.5	27.8	19.3	8.1	9.2	-0.6
Corn&Casein	27.3	26.4	19.0	7.4	27.6	19.0	8.2	9.3	-0.8
Corn&Casein	32.3	31.8	21.4	10.4	33.1	22.5	10.1	11.5	0.3
Corn&Casein	34.2	38.7	30.0	8.7	40.3	27.8	11.9	13.5	-3.3
Corn&Casein	27.9	33.2	25.3	7.9	34.6	24.5	9.6	11.0	-1.7
Corn&Casein	29.5	30.7	22.3	8.3	32.0	22.1	9.4	10.7	-1.1
Corn&Casein	31.9	31.1	22.3	8.8	32.4	22.0	10.0	11.3	-1.1
Corn&Casein	33.0	30.6	24.0	6.6	31.9	21.4	10.1	11.4	-3.5
RS&Casein	27.8	32.3	23.7	8.6	32.4	20.4	12.6	12.7	-4.0
RS&Casein	27.6	36.1	24.8	11.3	36.3	23.4	13.6	13.7	-2.3
RS&Casein	27.7	24.8	15.8	9.0	24.9	14.9	10.4	10.5	-1.4
RS&Casein	22.0	32.0	24.5	7.5	32.1	21.4	11.3	11.5	-3.9
RS&Casein	25.6	32.7	23.3	9.4	32.9	21.3	12.3	12.4	-2.8
RS&Casein	28.1	36.0	27.1	8.9	36.2	23.3	13.6	13.8	-4.7
RS&Casein	35.8	42.9	30.4	12.5	43.1	26.6	17.3	17.5	-4.8
RS&Casein	26.7	31.4	21.6	9.8	31.5	20.0	12.2	12.3	-2.3
RS&Casein	18.3	22.1	14.5	7.6	22.2	14.5	8.1	8.2	-0.5
RS&Casein	35.6	38.3	26.1	12.2	38.5	23.3	15.9	16.0	-3.7
RS&Casein	23.5	20.3	14.0	6.2	20.3	12.2	8.6	8.6	-2.3
RS&Casein	38.5	38.9	27.5	11.4	39.1	23.2	16.6	16.7	-5.2
WS&Casein	24.1	25.3	18.1	7.2	25.3	16.1	9.8	9.8	-2.6
WS&Casein	18.5	20.6	14.7	5.9	20.6	13.5	7.6	7.5	-1.6
WS&Casein	22.5	28.6	21.5	7.2	28.6	19.1	10.3	10.3	-3.1
WS&Casein	29.2	28.8	19.1	9.7	28.8	17.7	11.7	11.7	-2.1
WS&Casein	23.6	29.0	20.3	8.8	29.0	19.2	10.6	10.6	-1.8
WS&Casein	31.2	35.4	23.0	12.4	35.4	22.3	13.9	13.9	-1.5
WS&Casein	27.3	34.8	25.6	9.2	34.8	22.7	12.9	12.9	-3.7
WS&Casein	31.7	33.0	22.6	10.4	33.0	20.5	13.2	13.2	-2.9
WS&Casein	30.1	39.3	26.5	12.7	39.3	25.6	14.6	14.6	-1.9
WS&Casein	30.2	41.5	27.1	14.3	41.5	27.2	15.3	15.3	-1.0
WS&Casein	29.8	26.7	18.1	8.6	26.7	16.0	11.3	11.3	-2.7
WS&Casein	29.4	34.0	24.1	10.0	34.0	21.7	13.1	13.1	-3.1
Mean	27.8	30.8	21.8	9.0	31.2	20.3	11.2	11.7	-2.2

Table A-28. *(continue)*

Experiment 9.1[b]		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
Corn-SBM	37.6	47.6	24.7	22.9	51.0	25.1	23.4	26.8	-0.5
Corn-SBM	33.6	43.1	25.4	17.7	46.2	23.0	21.0	24.1	-3.3
Corn-SBM	32.7	41.3	22.1	19.1	44.2	22.1	20.0	23.0	-0.9
Corn-SBM	28.1	38.6	21.1	17.6	41.4	21.2	18.2	21.0	-0.7
Corn-SBM	23.6	42.4	25.1	17.4	45.5	24.6	18.7	21.8	-1.4
CS1+Corn&SBM	36.7	45.9	24.4	21.5	50.1	27.1	19.8	24.0	1.7
CS1+Corn&SBM	29.5	41.9	24.1	17.8	45.7	26.0	16.9	20.7	0.9
CS1+Corn&SBM	33.6	38.5	17.7	20.8	42.0	22.7	16.7	20.2	4.1
CS1+Corn&SBM	24.9	42.9	28.9	13.9	46.8	27.7	16.2	20.1	-2.3
CS1+Corn&SBM	30.4	38.4	22.3	16.2	42.0	23.1	16.2	19.7	0.0
CS2+Corn&SBM	38.1	47.6	29.1	18.5	50.7	28.7	19.9	23.0	-1.4
CS2+Corn&SBM	32.2	43.1	23.9	19.2	45.9	26.6	17.5	20.3	1.7
CS2+Corn&SBM	36.3	40.6	21.8	18.8	43.3	23.9	17.6	20.2	1.2
CS2+Corn&SBM	28.6	37.8	22.7	15.2	40.3	23.5	15.3	17.7	-0.1
CS2+Corn&SBM	24.5	44.3	30.3	14.0	47.1	29.4	16.0	18.9	-2.0
Corn&SBM+Hl	38.5	44.3	24.4	19.9	49.9	24.1	21.1	26.8	-1.3
Corn&SBM+Hl	35.8	39.8	22.6	17.3	44.9	21.8	18.9	24.0	-1.6
Corn&SBM+Hl	31.7	38.9	17.1	21.8	43.9	21.8	17.9	22.9	3.9
Corn&SBM+Hl	26.8	36.8	19.2	17.6	41.6	21.5	16.2	20.9	1.4
Corn&SBM+Hl	22.2	41.0	17.7	23.3	46.3	25.7	16.2	21.5	7.0
Mean	31.3	41.8	23.2	18.5	45.4	24.5	18.2	21.9	0.3

Table A-28. *(continue)*

Experiment 9.2[c]		Experiment			Simulation				
	Wt	NIT	NRet	NExc	NIT	NRet	NExc1	NExc2	DFNExc
Corn-SBM	43.1	51.0	24.4	26.6	54.6	26.1	25.9	29.6	0.7
Corn-SBM	36.7	50.8	29.6	21.2	54.4	27.0	24.8	28.4	-3.6
Corn-SBM	46.3	52.4	26.1	26.3	56.1	26.1	27.2	31.0	-1.0
Corn-SBM	40.8	58.6	30.1	28.5	62.7	31.1	28.7	32.9	-0.2
Corn-SBM	34.0	49.1	24.9	24.3	52.6	26.5	23.6	27.1	0.6
CS1+Corn&SBM	45.8	52.6	31.8	20.9	57.4	29.7	24.1	28.9	-3.2
CS1+Corn&SBM	37.6	51.8	29.9	21.9	56.5	30.8	22.2	26.9	-0.3
CS1+Corn&SBM	40.8	55.8	27.9	27.9	60.9	33.0	24.1	29.2	3.9
CS1+Corn&SBM	39.5	51.1	26.6	24.6	55.8	30.2	22.1	26.8	2.5
CS1+Corn&SBM	34.0	51.7	26.1	25.6	56.4	31.7	21.2	25.9	4.4
CS2+Corn&SBM	45.4	57.5	30.2	27.3	61.3	33.5	25.3	29.0	2.0
CS2+Corn&SBM	41.3	52.0	24.8	27.2	55.4	30.9	22.2	25.6	5.0
CS2+Corn&SBM	45.4	56.1	30.0	26.1	59.7	32.6	24.7	28.3	1.4
CS2+Corn&SBM	33.6	48.8	27.1	21.7	52.0	30.1	19.8	23.0	1.9
CS2+Corn&SBM	38.1	53.5	26.8	26.7	57.0	32.6	22.2	25.7	4.5
Corn&SBM+Hl	47.6	53.9	32.6	21.3	60.8	28.4	26.6	33.5	-5.2
Corn&SBM+Hl	43.1	52.8	26.8	26.0	59.5	28.6	25.3	32.1	0.7
Corn&SBM+Hl	40.8	58.2	30.3	28.0	65.7	32.4	27.0	34.5	1.0
Corn&SBM+Hl	35.4	47.7	24.8	22.9	53.8	26.8	21.9	28.0	1.0
Corn&SBM+Hl	29.0	44.1	26.4	17.7	49.7	25.9	19.2	24.8	-1.5
Mean	39.9	52.5	27.8	24.6	57.1	29.7	23.9	28.6	0.7

[a] Wt is the initial body weight on day 0 of the collection period in kg. NIT is the daily N intake in grams per day. NRet is the daily N retention in grams per day. NExc1 is the N excretion in grams per day obtained from the actual N intake and simulated N retention. Nexc2 is the N excretion in grams per day obtained from the calculated N intake and simulated N retention. DFNExc is the difference in N excretion in grams per day between actual and simulation value calculated by the actual N intake; i.e. DFNExc = actual NIT – Simulated NRet.

[b]Data concerning Experiment 9-1 corresponds to the first collection period of the experiment 9.

[c]Data concerning Experiment 9-2 corresponds to the second collection period of the experiment 9.

Table A- 29. The Average Experimental and Estimated Values of P Intake, Retention, and Excretion for Different Diet.

Experiment 1		Experiment			Simulation				
	Wt[a]	PIT	PHR	PExc	PIT	PHR	PExc1	PExc2	DFPExc
CS&Casein	29.6	3.5	3.0	0.5	3.7	3.3	0.2	0.5	0.3
CS&Casein	26.3	3.9	3.4	0.5	4.2	3.8	0.1	0.4	0.4
CS&Casein	35.2	3.8	3.0	0.8	4.1	3.4	0.4	0.7	0.3
CS&Casein	27.0	4.3	3.7	0.6	4.6	4.2	0.1	0.5	0.4
CS&Casein	33.6	4.4	4.2	0.2	4.7	3.9	0.5	0.8	-0.3
CS&Casein	28.3	4.8	4.2	0.7	5.2	4.6	0.2	0.6	0.4
Corn+CS&Casein	28.5	5.7	3.7	2.0	7.1	5.0	0.7	2.1	1.3
Corn+CS&Casein	33.0	5.9	4.0	1.9	7.4	5.0	0.9	2.4	0.9
Corn+CS&Casein	31.3	5.1	3.2	2.0	6.4	4.4	0.8	2.0	1.2
Corn+CS&Casein	21.2	5.7	3.7	2.0	7.1	5.7	0.0	1.4	2.0
Corn+CS&Casein	30.3	5.6	3.6	2.0	7.0	4.9	0.7	2.1	1.3
CS&Casein+SBM	31.9	7.0	4.8	2.1	7.5	5.0	2.0	2.5	0.2
CS&Casein+SBM	30.6	6.1	3.7	2.4	6.5	4.4	1.7	2.1	0.7
CS&Casein+SBM	26.7	6.6	4.6	2.0	7.1	5.1	1.5	2.0	0.5
CS&Casein+SBM	30.6	6.3	4.0	2.3	6.7	4.6	1.7	2.1	0.6
CS&Casein+SBM	31.8	4.4	2.9	1.5	4.7	3.2	1.2	1.6	0.2
Corn-SBM	26.1	7.4	4.4	3.0	7.4	4.5	2.9	2.9	0.1
Corn-SBM	26.6	9.9	5.9	4.1	9.9	6.0	3.9	4.0	0.1
Corn-SBM	31.7	9.9	5.7	4.2	9.9	5.6	4.3	4.3	-0.1
Corn-SBM	22.1	8.4	4.8	3.6	8.4	5.5	2.9	2.9	0.7
Corn-SBM	30.6	8.8	5.5	3.3	8.8	5.1	3.7	3.7	-0.4
Corn-SBM	32.6	10.2	6.9	3.2	10.2	5.7	4.5	4.5	-1.2
Mean	29.4	6.3	4.2	2.0	6.8	4.7	1.6	2.1	0.4

Table A-29. *(continue)*

Experiment 2		Experiment			Simulation				
	Wt[a]	PIT	PHR	PExc	PIT	PHR	PExc1	PExc2	DFPExc
CS&SBM	34.0	6.9	5.3	1.6	7.7	4.6	2.3	3.1	-0.7
CS&SBM	44.4	8.1	6.2	1.9	9.0	4.9	3.2	4.1	-1.4
CS&SBM	31.7	6.5	4.0	2.5	7.2	4.4	2.1	2.8	0.4
CS&SBM	41.3	8.5	4.9	3.6	9.5	5.2	3.3	4.3	0.3
CS&SBM	30.2	6.3	4.9	1.4	7.0	4.4	1.9	2.6	-0.5
CS&SBM	45.4	8.3	5.3	3.0	9.2	4.9	3.4	4.3	-0.4
CS&SBMH	30.8	9.0	6.2	2.8	8.6	5.5	3.5	3.1	-0.7
CS&SBMH	43.8	8.1	6.0	2.1	7.7	4.4	3.7	3.3	-1.6
CS&SBMH	37.2	9.0	5.4	3.7	8.6	5.2	3.8	3.4	-0.2
CS&SBMH	33.6	8.1	5.2	2.9	7.8	4.9	3.2	2.9	-0.4
CS&SBMH	42.2	10.2	6.2	4.0	9.7	5.6	4.6	4.1	-0.6
CS&SBMH	39.0	8.8	6.0	2.8	8.4	5.0	3.8	3.4	-1.0
CS&SPC	36.1	6.5	4.1	2.4	6.9	4.4	2.1	2.4	0.3
CS&SPC	38.1	7.8	5.2	2.6	8.3	5.2	2.6	3.1	0.1
CS&SPC	32.7	7.5	5.7	1.8	7.9	5.3	2.2	2.6	-0.4
CS&SPC	39.5	6.4	4.8	1.7	6.8	4.3	2.1	2.5	-0.4
CS&SPC	34.5	5.1	4.3	0.8	5.5	3.6	1.5	1.9	-0.7
CS&SPC	34.0	6.8	4.3	2.5	7.2	4.8	2.0	2.4	0.5
CS&SPI	36.3	5.8	4.3	1.5	5.4	3.8	2.0	1.6	-0.5
CS&SPI	30.6	5.0	3.0	2.0	4.7	3.5	1.5	1.2	0.5
CS&SPI	31.3	6.2	4.4	1.9	5.7	4.3	1.9	1.5	-0.1
CS&SPI	42.2	6.6	4.2	2.4	6.1	4.1	2.5	2.0	-0.1
CS&SPI	38.1	7.8	5.5	2.3	7.3	5.0	2.8	2.2	-0.5
CS&SPI	38.1	6.6	5.5	1.1	6.1	4.2	2.4	1.8	-1.3
Mean	36.9	7.3	5.0	2.3	7.4	4.6	2.7	2.8	-0.4

Table A-29. *(continue)*

Experiment 5		Experiment			Simulation				
	Wt	PIT	PHR	PExc	PIT	PHR	PExc1	PExc2	DFPExc
CS&Casein	23.7	3.3	2.6	0.7	4.5	2.2	1.1	2.4	-0.4
CS&Casein	20.9	3.1	1.9	1.2	4.3	2.1	1.0	2.1	0.2
CS&Casein	24.1	2.8	1.9	0.8	3.8	1.8	1.0	2.0	-0.1
CS&Casein	20.9	3.3	2.6	0.6	4.4	2.2	1.0	2.2	-0.4
CS&Casein	20.7	2.8	1.7	1.1	3.9	2.0	0.9	1.9	0.2
CS&Casein	16.2	2.7	2.0	0.7	3.7	2.0	0.7	1.7	0.0
Corn-SBM	14.9	6.6	4.0	2.7	7.6	5.0	1.6	2.6	1.0
Corn-SBM	21.8	9.1	4.7	4.3	10.3	5.7	3.4	4.7	0.9
Corn-SBM	22.4	7.8	4.5	3.3	8.9	5.0	2.8	3.9	0.6
Corn-SBM	26.5	8.8	5.1	3.6	10.0	5.3	3.4	4.7	0.2
Corn-SBM	26.7	9.3	5.8	3.5	10.6	5.6	3.6	4.9	-0.1
Corn-SBM	24.7	8.5	5.5	3.0	9.7	5.3	3.2	4.4	-0.2
LPAA	26.5	8.7	5.4	3.3	9.8	5.3	3.4	4.5	-0.1
LPAA	24.3	8.7	4.1	4.6	9.7	5.5	3.1	4.2	1.5
LPAA	22.8	7.7	4.3	3.4	8.7	5.0	2.7	3.7	0.7
LPAA	22.0	7.8	5.1	2.7	8.8	5.1	2.7	3.7	0.1
LPAA	22.6	8.5	5.6	2.9	9.6	5.6	2.9	4.0	0.0
LPAA	20.0	5.6	2.9	2.7	6.3	3.9	1.7	2.5	0.9
Corn&SPC	27.5	8.3	4.8	3.5	7.7	4.3	4.0	3.4	-0.4
Corn&SPC	22.9	9.1	6.1	3.0	8.5	5.0	4.1	3.4	-1.1
Corn&SPC	24.3	10.9	7.2	3.7	10.1	5.9	5.0	4.3	-1.3
Corn&SPC	22.9	9.1	4.8	4.3	8.4	5.0	4.1	3.4	0.2
Corn&SPC	22.3	10.1	7.1	2.9	9.3	5.6	4.5	3.8	-1.6
Corn&SPC	24.0	9.9	7.2	2.7	9.1	5.4	4.4	3.7	-1.8
Mean	22.7	7.2	4.5	2.7	7.8	4.4	2.8	3.4	0.0

[a] Wt is the initial body weight on day 0 of the collection period in kg. PIT is the daily total P intake in grams per day. PHR is the daily P retention in grams per day. PExc1 is the P excretion in grams per day obtained from the actual total P intake and simulated P retention. Pexc2 is the P excretion in grams per day obtained from the calculated total P intake and simulated P retention. DFPExc is the difference in P excretion in grams per day between actual and simulation value calculated by the actual total P intake; i.e. DFPExc = Actual PIT – Simulated PHR.

Table A- 30. Daily growth levels for different simulation models under P restriction when applicable land was adequate.

	Lab w/o Adj				Farm w/o Adj				Farm w Adj			
D[a]	Wt[b] kg	ADG[c] g	PR[d] g	PHR[e] g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
1	20.0	707.1	131.1	3.2	20.00	633.28	103.10	3.27	20.0	597.1	96.9	3.6
2	20.7	726.4	134.5	3.3	20.63	648.37	105.32	3.31	20.6	610.7	98.9	3.6
3	21.4	745.8	137.9	3.4	21.28	663.53	107.53	3.36	21.2	624.3	100.9	3.7
4	22.2	765.3	141.3	3.5	21.95	678.75	109.73	3.40	21.8	638.1	102.9	3.7
5	22.9	785.0	144.7	3.6	22.62	694.01	111.93	3.45	22.5	651.8	104.9	3.8
6	23.7	804.7	148.1	3.7	23.32	709.31	114.12	3.49	23.1	665.6	106.8	3.8
7	24.5	824.5	151.5	3.7	24.03	724.62	116.30	3.54	23.8	679.5	108.8	3.9
8	25.4	844.3	154.8	3.8	24.75	739.93	118.47	3.58	24.5	693.3	110.7	3.9
9	26.2	864.1	158.2	3.9	25.49	755.23	120.62	3.63	25.2	707.1	112.7	4.0
10	27.1	883.9	161.6	4.0	26.25	770.50	122.75	3.67	25.9	720.9	114.6	4.1
11	28.0	903.7	164.9	4.1	27.02	785.73	124.86	3.71	26.6	734.7	116.5	4.1
12	28.9	923.4	168.3	4.2	27.80	800.91	126.94	3.79	27.3	748.5	118.4	4.2
13	29.8	943.1	171.6	4.3	28.60	816.02	129.00	3.87	28.1	762.2	120.3	4.2
14	30.7	962.7	174.9	4.4	29.42	831.05	131.04	3.95	28.8	775.8	122.1	4.3
15	31.7	982.1	178.1	4.5	30.25	845.99	133.05	4.02	29.6	789.4	123.9	4.3
16	32.7	1001.5	181.3	4.6	31.10	860.82	135.02	4.10	30.4	802.9	125.7	4.4
17	33.7	1020.6	184.5	4.7	31.96	875.52	136.97	4.18	31.2	816.3	127.5	4.5
18	34.7	1039.6	187.6	4.7	32.83	890.10	138.88	4.25	32.0	829.6	129.3	4.5
19	35.7	1058.4	190.7	4.8	33.72	904.53	140.76	4.33	32.9	842.8	131.0	4.6
20	36.8	1077.0	193.7	4.9	34.63	918.81	142.60	4.41	33.7	855.8	132.7	4.6
21	37.9	1095.4	196.7	5.0	35.55	932.92	144.40	4.48	34.6	868.8	134.3	4.7
22	39.0	1113.5	199.6	5.1	36.48	946.85	146.16	4.56	35.4	881.6	136.0	4.7
23	40.1	1131.3	202.5	5.2	37.43	960.60	147.88	4.63	36.3	894.2	137.5	4.8
24	41.2	1148.9	205.3	5.3	38.39	974.15	149.57	4.71	37.2	906.7	139.1	4.8
25	42.4	1166.2	208.1	5.4	39.36	987.49	151.21	4.78	38.1	919.0	140.6	4.9
26	43.5	1183.1	210.8	5.4	40.35	1000.63	152.80	4.86	39.0	931.2	142.1	4.9
27	44.7	1199.8	213.4	5.5	41.35	1013.54	154.36	4.93	40.0	943.2	143.6	5.0
28	45.9	1216.1	216.0	5.6	42.36	1026.23	155.87	5.00	40.9	955.0	145.0	5.0
29	47.1	1232.1	218.5	5.7	43.39	1038.68	157.34	5.07	41.9	966.6	146.4	5.1
30	48.4	1247.8	220.9	5.8	44.43	1050.90	158.77	5.14	42.8	978.0	147.7	5.1
31	49.6	1263.0	223.3	5.8	45.48	1062.86	160.15	5.21	43.8	989.1	149.0	5.2
32	50.9	1278.0	225.6	5.9	46.54	1074.58	161.48	5.28	44.8	1000.1	150.2	5.3
33	52.1	1292.5	227.9	6.0	47.62	1086.05	162.78	5.35	45.8	1010.8	151.5	5.3
34	53.4	1306.7	230.1	6.1	48.70	1097.26	164.02	5.42	46.8	1021.4	152.7	5.4
35	54.7	1320.5	232.2	6.1	49.80	1108.21	165.23	5.49	47.8	1031.7	153.8	5.5
36	56.1	1334.0	234.2	6.2	50.91	1118.90	166.39	5.55	48.8	1041.8	154.9	5.5
37	57.4	1347.0	236.2	6.3	52.03	1129.32	167.51	5.62	49.9	1051.7	156.0	5.6
38	58.7	1359.7	238.1	6.3	53.16	1139.48	168.59	5.68	50.9	1061.3	157.0	5.7
39	60.1	1372.0	240.0	6.4	54.30	1149.37	169.62	5.74	52.0	1070.7	158.0	5.8

Table A-30 *(continue)*

	Lab w/o Adj				Farm w/o Adj				Farm w Adj			
D[a]	Wt[b] kg	ADG[c] g	PR[d] g	PHR[e] g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
40	61.5	1383.8	241.7	6.5	55.45	1159.00	170.61	5.81	53.1	1079.9	159.0	5.8
41	62.9	1395.3	243.5	6.5	56.60	1168.35	171.57	5.87	54.2	1088.9	159.9	5.9
42	64.3	1406.5	245.1	6.6	57.77	1177.44	172.48	5.93	55.2	1097.6	160.8	6.0
43	65.7	1417.2	246.7	6.7	58.95	1186.27	173.35	5.99	56.3	1106.1	161.7	6.0
44	67.1	1427.6	248.2	6.7	60.14	1194.82	174.18	6.04	57.4	1114.4	162.5	6.1
45	68.5	1437.5	249.7	6.8	61.33	1203.12	174.98	6.10	58.6	1122.5	163.3	6.2
46	69.9	1447.2	251.1	6.8	62.53	1211.15	175.74	6.16	59.7	1130.3	164.1	6.2
47	71.4	1456.4	252.5	6.9	63.75	1218.92	176.46	6.21	60.8	1137.9	164.8	6.3
48	72.8	1465.3	253.8	6.9	64.96	1226.44	177.15	6.27	62.0	1145.2	165.5	6.4
49	74.3	1473.8	255.0	7.0	66.19	1233.69	177.80	6.32	63.1	1152.4	166.1	6.4
50	75.8	1481.9	256.2	7.1	67.42	1240.70	178.42	6.37	64.2	1159.3	166.8	6.5
51	77.3	1489.7	257.3	7.1	68.66	1247.46	179.01	6.42	65.4	1166.0	167.4	6.6
52	78.8	1497.2	258.4	7.1	69.91	1253.97	179.56	6.47	66.6	1172.4	167.9	6.6
53	80.3	1504.3	259.4	7.2	71.17	1260.24	180.09	6.52	67.7	1178.7	168.5	6.7
54	81.8	1511.1	260.4	7.2	72.43	1266.26	180.58	6.57	68.9	1184.7	169.0	6.7
55	83.3	1517.5	261.3	7.3	73.69	1272.06	181.05	6.62	70.1	1190.5	169.5	6.8
56	84.8	1523.7	262.2	7.3	74.96	1277.62	181.49	6.66	71.3	1196.2	169.9	6.8
57	86.3	1529.5	263.1	7.4	76.24	1282.95	181.90	6.71	72.5	1201.6	170.4	6.9
58	87.8	1535.0	263.8	7.4	77.53	1288.06	182.28	6.75	73.7	1206.8	170.8	7.0
59	89.4	1540.2	264.6	7.5	78.81	1292.95	182.64	6.79	74.9	1211.8	171.2	7.0
60	90.9	1545.1	265.3	7.5	80.11	1297.62	182.98	6.84	76.1	1216.6	171.5	7.1
61	92.5	1549.8	266.0	7.5	81.40	1302.08	183.29	6.88	77.3	1221.2	171.9	7.1
62	94.0	1554.1	266.6	7.6	82.71	1306.34	183.58	6.92	78.6	1225.6	172.2	7.2
63	95.6	1558.2	267.2	7.6	84.01	1310.39	183.84	6.96	79.8	1229.8	172.5	7.2
64	97.1	1562.0	267.7	7.6	85.32	1314.24	184.09	6.99	81.0	1233.9	172.8	7.3
65	98.7	1565.5	268.3	7.7	86.64	1317.90	184.32	7.03	82.2	1237.7	173.0	7.3
66	100.3	1568.8	268.7	7.7	87.96	1321.37	184.52	7.07	83.5	1241.4	173.3	7.4
67	101.8	1571.8	269.2	7.7	89.28	1324.65	184.71	7.10	84.7	1245.0	173.5	7.4
68	103.4	1574.6	269.6	7.8	90.60	1327.76	184.88	7.14	86.0	1248.3	173.7	7.4
69	105.0	1577.2	270.0	7.8	91.93	1330.68	185.03	7.17	87.2	1251.5	173.9	7.5
70	106.5	1579.5	270.3	7.8	93.26	1333.43	185.17	7.21	88.5	1254.5	174.1	7.5
71	108.1	1581.7	270.7	7.8	94.59	1336.01	185.29	7.24	89.7	1257.3	174.2	7.6
72	109.7	1583.6	271.0	7.9	95.93	1338.43	185.39	7.27	91.0	1260.0	174.3	7.6
73	111.3	1585.3	271.2	7.9	97.27	1340.69	185.48	7.30	92.2	1262.6	174.5	7.7
74	112.9	1586.7	271.5	7.9	98.61	1342.79	185.56	7.33	93.5	1265.0	174.6	7.7
75	114.5	1588.0	271.7	7.9	99.95	1344.73	185.62	7.36	94.8	1267.2	174.7	7.7
76	116.0	1589.1	271.9	8.0	101.30	1346.53	185.67	7.39	96.0	1269.3	174.8	7.8
77	117.6	1590.1	272.0	8.0	102.64	1348.19	185.70	7.42	97.3	1271.3	174.8	7.8
78	119.2	1590.8	272.2	8.0	103.99	1349.70	185.73	7.44	98.6	1273.1	174.9	7.8
79					105.34	1351.07	185.74	7.47	99.8	1274.8	174.9	7.9

Table A-30 (*continue*)

D[a]	Lab w/o Adj				Farm w/o Adj				Farm w Adj			
	Wt[b] kg	ADG[c] g	PR[d] g	PHR[e] g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
80					106.69	1352.32	185.75	7.50	101.1	1276.4	175.0	7.9
81					108.04	1353.43	185.74	7.52	102.4	1277.8	175.0	7.9
82					109.40	1354.41	185.72	7.55	103.7	1279.2	175.0	8.0
83					110.75	1355.28	185.69	7.57	105.0	1280.3	175.0	8.0
84					112.11	1356.02	185.66	7.59	106.2	1281.4	175.0	8.0
85					113.46	1356.65	185.61	7.62	107.5	1282.4	175.0	8.1
86					114.82	1357.16	185.56	7.64	108.8	1283.2	175.0	8.1
87					116.18	1357.57	185.50	7.66	110.1	1284.0	174.9	8.1
88					117.53	1357.87	185.43	7.68	111.4	1284.6	174.9	8.2
89					118.89	1358.06	185.35	7.70	112.7	1285.2	174.8	8.2
90									113.9	1285.6	174.8	8.2
91									115.2	1285.9	174.7	8.2
92									116.5	1286.2	174.7	8.3
93									117.8	1286.3	174.6	8.3
94									119.1	1286.6	174.7	8.4

[a] D = growing period, in day.
[b] Wt = pig body weight in kilograms.
[c] ADG= daily body Weight gain in grams per day.
[d] PR= daily protein retention in grams per day.
[c] PHR= daily phosphorus retention in grams per day.

Table A- 31. Daily nutrient intake and excretion levels for different simulation models under P restriction when applicable land was adequate.

	Lab w/o Adj					Farm w/o Adj					Farm w Adj				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
1	57.29	7.13	0.08	0.01	0.14	43.09	6.88	0.06	0.01	0.23	42.64	7.07	0.06	0.01	0.23
2	58.72	7.32	0.09	0.01	0.15	44.06	7.02	0.06	0.01	0.24	43.67	7.21	0.07	0.01	0.24
3	60.16	7.52	0.09	0.01	0.15	45.03	7.16	0.07	0.01	0.25	44.71	7.35	0.07	0.01	0.24
4	61.60	7.72	0.09	0.01	0.16	46.00	7.29	0.07	0.01	0.25	45.75	7.50	0.07	0.01	0.25
5	63.04	7.91	0.09	0.01	0.16	46.98	7.43	0.07	0.01	0.26	46.81	7.64	0.07	0.01	0.26
6	64.48	8.12	0.09	0.01	0.17	47.95	7.57	0.07	0.01	0.27	47.88	7.79	0.07	0.01	0.26
7	65.91	8.32	0.10	0.01	0.17	48.92	7.70	0.07	0.01	0.28	48.96	7.94	0.07	0.01	0.27
8	67.35	8.52	0.10	0.01	0.18	49.89	7.84	0.07	0.01	0.29	50.05	8.09	0.08	0.01	0.28
9	68.77	8.72	0.10	0.01	0.18	50.86	7.98	0.07	0.01	0.29	51.14	8.24	0.08	0.01	0.29
10	70.19	8.92	0.10	0.01	0.19	51.82	8.11	0.08	0.01	0.30	52.24	8.38	0.08	0.01	0.29
11	71.59	9.13	0.10	0.01	0.20	52.78	8.25	0.08	0.01	0.31	53.34	8.53	0.08	0.01	0.30
12	72.99	9.33	0.11	0.01	0.20	53.73	8.43	0.08	0.01	0.32	54.45	8.69	0.08	0.01	0.31
13	74.37	9.53	0.11	0.01	0.21	54.68	8.60	0.08	0.01	0.33	55.57	8.84	0.08	0.01	0.32
14	75.74	9.74	0.11	0.01	0.22	55.61	8.77	0.08	0.01	0.34	56.69	8.99	0.09	0.01	0.33
15	77.09	9.94	0.11	0.01	0.22	56.54	8.94	0.08	0.01	0.35	57.81	9.14	0.09	0.01	0.34
16	78.43	10.14	0.11	0.01	0.23	57.47	9.11	0.08	0.01	0.35	58.93	9.29	0.09	0.01	0.34
17	79.74	10.34	0.12	0.01	0.24	58.38	9.28	0.09	0.01	0.36	60.06	9.44	0.09	0.01	0.35
18	81.04	10.54	0.12	0.01	0.25	59.28	9.46	0.09	0.01	0.37	61.19	9.59	0.09	0.01	0.36
19	82.31	10.74	0.12	0.01	0.25	60.17	9.63	0.09	0.01	0.38	62.31	9.74	0.10	0.01	0.37
20	83.57	10.94	0.12	0.01	0.26	61.05	9.80	0.09	0.01	0.39	63.44	9.89	0.10	0.01	0.38
21	84.80	11.13	0.12	0.01	0.27	61.92	9.96	0.09	0.01	0.40	64.57	10.04	0.10	0.01	0.39
22	86.00	11.33	0.13	0.01	0.27	62.77	10.13	0.09	0.01	0.41	65.69	10.19	0.10	0.01	0.40
23	87.18	11.52	0.13	0.01	0.28	63.61	10.30	0.09	0.01	0.42	66.81	10.34	0.10	0.01	0.41
24	88.34	11.71	0.13	0.01	0.29	64.44	10.47	0.10	0.01	0.43	67.92	10.49	0.11	0.01	0.42
25	89.46	11.90	0.13	0.01	0.30	65.26	10.63	0.10	0.01	0.44	69.04	10.64	0.11	0.01	0.42
26	90.57	12.08	0.13	0.01	0.31	66.06	10.79	0.10	0.01	0.45	70.14	10.78	0.11	0.01	0.43
27	91.64	12.26	0.13	0.01	0.31	66.84	10.96	0.10	0.01	0.46	71.17	10.93	0.11	0.01	0.44
28	92.68	12.44	0.14	0.02	0.32	67.61	11.12	0.10	0.01	0.47	72.34	11.07	0.11	0.01	0.45
29	93.70	12.62	0.14	0.02	0.33	68.36	11.28	0.10	0.01	0.48	73.43	11.22	0.12	0.01	0.46
30	94.69	12.80	0.14	0.02	0.34	69.10	11.43	0.10	0.01	0.49	74.51	11.36	0.12	0.01	0.47
31	95.65	12.97	0.14	0.02	0.35	69.82	11.59	0.10	0.01	0.50	75.24	11.49	0.12	0.01	0.48
32	96.58	13.14	0.14	0.02	0.35	70.53	11.74	0.11	0.01	0.51	76.30	11.66	0.12	0.01	0.49
33	97.48	13.31	0.14	0.02	0.36	71.22	11.89	0.11	0.01	0.52	77.36	11.83	0.12	0.01	0.50
34	98.36	13.47	0.14	0.02	0.37	71.90	12.05	0.11	0.01	0.53	78.40	11.99	0.13	0.01	0.51
35	99.20	13.63	0.14	0.02	0.38	72.55	12.19	0.11	0.01	0.54	79.43	12.16	0.13	0.01	0.52
36	100.02	13.79	0.15	0.02	0.38	73.20	12.34	0.11	0.01	0.55	80.46	12.32	0.13	0.01	0.53
37	100.81	13.94	0.15	0.02	0.39	73.82	12.48	0.11	0.02	0.56	81.47	12.48	0.13	0.02	0.54
38	101.57	14.09	0.15	0.02	0.40	74.43	12.63	0.11	0.02	0.57	82.49	12.64	0.13	0.02	0.55

Table A-31 *(continue)*

	Lab w/o Adj					Farm w/o Adj					Farm w Adj				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
39	102.30	14.24	0.15	0.02	0.41	75.02	12.77	0.11	0.02	0.58	83.48	12.80	0.14	0.02	0.56
40	103.01	14.39	0.15	0.02	0.42	75.60	12.90	0.11	0.02	0.59	84.46	12.96	0.14	0.02	0.57
41	103.68	14.53	0.15	0.02	0.42	76.16	13.04	0.11	0.02	0.60	85.41	13.11	0.14	0.02	0.58
42	104.34	14.67	0.15	0.02	0.43	76.71	13.17	0.12	0.02	0.61	86.37	13.26	0.14	0.02	0.58
43	104.96	14.80	0.15	0.02	0.44	77.24	13.30	0.12	0.02	0.62	87.31	13.41	0.14	0.02	0.59
44	105.57	14.93	0.15	0.02	0.45	77.76	13.43	0.12	0.02	0.63	88.21	13.56	0.14	0.02	0.60
45	106.14	15.06	0.15	0.02	0.45	78.26	13.56	0.12	0.02	0.63	89.13	13.71	0.15	0.02	0.61
46	106.69	15.19	0.16	0.02	0.46	78.74	13.68	0.12	0.02	0.64	90.03	13.85	0.15	0.02	0.62
47	107.22	15.31	0.16	0.02	0.47	79.21	13.81	0.12	0.02	0.65	90.91	14.00	0.15	0.02	0.63
48	107.73	15.43	0.16	0.02	0.48	79.67	13.93	0.12	0.02	0.66	91.79	14.14	0.15	0.02	0.64
49	108.21	15.54	0.16	0.02	0.48	80.11	14.04	0.12	0.02	0.67	92.65	14.28	0.15	0.02	0.65
50	108.67	15.66	0.16	0.02	0.49	80.54	14.16	0.12	0.02	0.68	93.49	14.42	0.16	0.02	0.66
51	109.11	15.77	0.16	0.02	0.50	80.95	14.27	0.12	0.02	0.69	94.39	14.55	0.16	0.02	0.67
52	109.53	15.87	0.16	0.02	0.51	81.35	14.38	0.12	0.02	0.70	95.16	14.68	0.16	0.02	0.67
53	109.93	15.98	0.16	0.02	0.51	81.74	14.49	0.12	0.02	0.71	95.97	14.82	0.16	0.02	0.68
54	110.31	16.08	0.16	0.02	0.52	82.12	14.60	0.13	0.02	0.72	96.72	14.94	0.16	0.02	0.69
55	110.67	16.18	0.16	0.02	0.53	82.48	14.70	0.13	0.02	0.72	97.49	15.07	0.16	0.02	0.70
56	111.01	16.27	0.16	0.02	0.53	82.83	14.80	0.13	0.02	0.73	98.30	15.20	0.17	0.02	0.71
57	111.34	16.37	0.16	0.02	0.54	83.17	14.90	0.13	0.02	0.74	99.04	15.32	0.17	0.02	0.72
58	111.64	16.46	0.16	0.02	0.55	83.49	15.00	0.13	0.02	0.75	99.78	15.44	0.17	0.02	0.73
59	111.93	16.54	0.16	0.02	0.55	83.81	15.10	0.14	0.02	0.76	100.47	15.56	0.17	0.02	0.73
60	112.21	16.63	0.16	0.02	0.56	84.11	15.19	0.14	0.02	0.77	101.22	15.68	0.17	0.02	0.74
61	112.47	16.71	0.16	0.02	0.57	84.40	15.28	0.14	0.02	0.77	101.91	15.79	0.17	0.02	0.75
62	112.71	16.79	0.16	0.02	0.57	84.69	15.37	0.14	0.02	0.78	102.63	15.90	0.17	0.02	0.76
63	112.94	16.87	0.16	0.02	0.58	84.96	15.46	0.14	0.02	0.79	103.23	16.01	0.18	0.02	0.76
64	113.16	16.94	0.16	0.02	0.58	85.22	15.54	0.14	0.02	0.80	103.88	16.12	0.18	0.02	0.77
65	113.36	17.02	0.16	0.02	0.59	85.48	15.63	0.14	0.02	0.80	104.52	16.22	0.18	0.02	0.78
66	113.55	17.09	0.17	0.02	0.60	85.72	15.71	0.14	0.02	0.81	105.15	16.33	0.18	0.02	0.79
67	113.72	17.16	0.17	0.02	0.60	85.95	15.79	0.14	0.02	0.82	105.76	16.43	0.18	0.02	0.79
68	113.89	17.22	0.17	0.02	0.61	86.18	15.86	0.14	0.02	0.83	106.35	16.53	0.18	0.02	0.80
69	114.04	17.28	0.17	0.02	0.61	86.40	15.94	0.14	0.02	0.83	106.94	16.63	0.18	0.02	0.81
70	114.18	17.35	0.17	0.02	0.62	86.61	16.01	0.14	0.02	0.84	107.51	16.72	0.19	0.02	0.82
71	114.32	17.41	0.17	0.02	0.62	86.81	16.09	0.14	0.02	0.85	108.06	16.82	0.19	0.02	0.82
72	114.44	17.46	0.17	0.02	0.63	87.00	16.16	0.14	0.02	0.85	108.61	16.91	0.19	0.02	0.83
73	114.60	17.52	0.17	0.02	0.63	87.18	16.23	0.14	0.02	0.86	109.14	17.00	0.19	0.02	0.84
74	114.82	17.58	0.17	0.02	0.64	87.36	16.29	0.14	0.02	0.87	109.67	17.09	0.19	0.02	0.84
75	115.03	17.64	0.17	0.02	0.64	87.53	16.36	0.14	0.02	0.87	110.17	17.17	0.19	0.02	0.85
76	115.22	17.70	0.17	0.02	0.65	87.70	16.42	0.14	0.02	0.88	110.67	17.26	0.19	0.02	0.86
77	115.41	17.76	0.17	0.02	0.65	87.86	16.48	0.14	0.02	0.88	111.16	17.34	0.19	0.02	0.86

Table A-31 (*continue*)

	Lab w/o Adj					Farm w/o Adj					Farm w Adj				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
78	115.58	17.81	0.17	0.02	0.66	88.01	16.54	0.14	0.02	0.89	111.63	17.42	0.19	0.02	0.87
79						88.15	16.60	0.14	0.02	0.90	112.09	17.50	0.20	0.02	0.87
80						88.29	16.66	0.15	0.02	0.90	112.54	17.58	0.20	0.02	0.88
81						88.42	16.72	0.15	0.02	0.91	112.99	17.65	0.20	0.02	0.89
82						88.55	16.77	0.15	0.02	0.91	113.42	17.73	0.20	0.02	0.89
83						88.67	16.82	0.14	0.02	0.92	113.84	17.80	0.20	0.02	0.90
84						88.79	16.88	0.14	0.02	0.92	114.25	17.87	0.20	0.02	0.90
85						88.90	16.93	0.14	0.02	0.93	114.65	17.94	0.20	0.02	0.91
86						89.01	16.98	0.14	0.02	0.93	115.03	18.01	0.20	0.02	0.91
87						89.11	17.02	0.14	0.02	0.94	115.41	18.07	0.20	0.02	0.92
88						89.20	17.07	0.15	0.02	0.94	115.78	18.14	0.20	0.02	0.92
89						89.30	17.12	0.15	0.02	0.95	116.15	18.20	0.20	0.02	0.93
90											116.50	18.26	0.21	0.02	0.93
91											116.84	18.32	0.21	0.02	0.94
92											117.17	18.38	0.21	0.02	0.94
93											117.51	18.44	0.21	0.02	0.95
94											119.81	18.61	0.21	0.02	0.95

[a] D = growing period, in day.

Table A- 32. Daily ration composition[a] for different simulation models under P restriction when applicable land was adequate.

	Lab w/o Adj				Farm w/o Adj				Farm w Adj			
D[b]	Corn	SBM	P[c]	L[d]	Corn	SBM	P	L	Corn	SBM	P	L
1	332.5	695.7	9.0	108.5	660.9	451.5	11.3	9.9	615.9	453.4	12.9	9.0
2	346.2	712.2	9.3	106.9	680.8	460.8	11.4	10.1	631.9	464.2	13.1	9.0
3	360.2	728.6	9.5	104.8	701.2	470.0	11.6	10.2	648.1	475.0	13.2	9.1
4	374.8	745.0	9.8	102.4	721.9	479.2	11.7	10.3	664.5	485.9	13.4	9.1
5	389.8	761.4	10.1	99.6	743.0	488.3	11.8	10.4	681.1	497.0	13.5	9.2
6	405.2	777.6	10.4	96.4	764.5	497.3	11.9	10.5	697.9	508.1	13.7	9.2
7	421.2	793.7	10.6	92.8	786.3	506.3	11.9	10.6	714.9	519.3	13.8	9.3
8	437.5	809.7	10.9	88.8	808.5	515.2	12.0	10.7	732.1	530.6	14.0	9.3
9	454.4	825.5	11.2	84.4	831.1	524.0	12.1	10.8	749.4	541.9	14.1	9.4
10	471.7	841.1	11.5	79.5	854.0	532.6	12.2	11.0	766.9	553.3	14.3	9.5
11	489.4	856.5	11.8	74.2	877.2	541.2	12.3	11.1	784.6	564.8	14.4	9.5
12	507.6	871.7	12.1	68.4	900.8	549.6	12.6	11.1	802.3	576.3	14.6	9.6
13	526.2	886.7	12.4	62.3	924.6	557.9	12.9	11.1	820.2	587.9	14.7	9.6
14	545.2	901.3	12.7	55.6	948.8	566.0	13.2	11.1	838.2	599.4	14.8	9.7
15	564.6	915.7	13.0	48.6	973.2	574.0	13.4	11.1	856.3	611.0	15.0	9.7
16	584.4	929.8	13.3	41.0	997.8	581.8	13.7	11.1	874.6	622.6	15.1	9.8
17	604.6	943.6	13.6	33.1	1022.7	589.4	14.0	11.1	892.9	634.3	15.2	9.8
18	625.2	957.1	13.9	24.7	1047.9	596.9	14.3	11.1	911.2	645.9	15.4	9.8
19	646.1	970.2	14.2	15.9	1073.2	604.2	14.6	11.1	929.7	657.5	15.5	9.9
20	667.3	983.0	14.5	8.9	1098.7	611.3	14.8	11.1	948.1	669.1	15.6	9.9
21	688.8	995.4	14.8	8.9	1124.5	618.2	15.1	11.1	966.7	680.6	15.7	10.0
22	710.7	1007.4	15.1	8.8	1150.3	625.0	15.4	11.1	985.2	692.2	15.9	10.0
23	732.8	1019.1	15.4	8.8	1176.3	631.5	15.7	11.0	1003.8	703.7	16.0	10.1
24	755.1	1030.4	15.7	8.7	1202.5	637.8	16.0	11.0	1022.4	715.1	16.1	10.1
25	777.7	1041.3	15.9	8.7	1228.7	643.9	16.2	11.0	1041.0	726.5	16.2	10.1
26	800.5	1051.8	16.2	8.7	1255.0	649.9	16.5	11.0	1059.5	737.8	16.3	10.2
27	823.4	1061.9	16.5	8.6	1281.4	655.6	16.8	11.0	1079.3	747.9	16.4	10.2
28	846.6	1071.6	16.8	8.6	1307.8	661.1	17.1	11.0	1096.6	760.2	16.5	10.3
29	869.8	1080.9	17.1	8.5	1334.3	666.4	17.3	10.9	1115.0	771.4	16.6	10.3
30	893.2	1089.8	17.4	8.5	1360.8	671.5	17.6	10.9	1133.5	782.4	16.7	10.3
31	916.7	1098.4	17.6	8.4	1387.3	676.3	17.9	10.9	1157.6	787.7	16.9	10.3
32	940.3	1106.5	17.9	8.4	1413.7	681.0	18.1	10.9	1175.9	798.5	17.2	10.3
33	963.9	1114.3	18.2	8.3	1440.1	685.5	18.4	10.8	1194.1	809.2	17.4	10.2
34	987.5	1121.6	18.5	8.3	1466.5	689.8	18.7	10.8	1212.2	819.8	17.7	10.1
35	1011.1	1128.6	18.7	8.2	1492.8	693.8	18.9	10.8	1230.3	830.2	17.9	10.1
36	1034.8	1135.2	19.0	8.1	1518.9	697.7	19.2	10.7	1248.2	840.6	18.2	10.0
37	1058.3	1141.5	19.2	8.1	1545.0	701.4	19.5	10.7	1266.0	850.8	18.4	9.9
38	1081.9	1147.4	19.5	8.0	1571.0	704.9	19.7	10.7	1283.4	861.1	18.6	9.8
39	1105.3	1152.9	19.7	8.0	1596.8	708.2	20.0	10.6	1300.9	871.1	18.9	9.7

Table A-32 *(continue*)

	Lab w/o Adj				Farm w/o Adj				Farm w Adj			
D[a]	Corn	SBM	P[b]	L[c]	Corn	SBM	P	L	Corn	SBM	P	L
40	1128.7	1158.1	20.0	7.9	1622.5	711.3	20.2	10.6	1318.3	881.0	19.1	9.7
41	1151.9	1163.0	20.2	7.8	1648.0	714.2	20.4	10.6	1335.9	890.4	19.4	9.6
42	1175.1	1167.5	20.5	7.8	1673.3	717.0	20.7	10.5	1352.9	900.0	19.6	9.5
43	1198.0	1171.8	20.7	7.7	1698.5	719.6	20.9	10.5	1369.8	909.5	19.8	9.4
44	1220.8	1175.7	20.9	7.7	1723.4	722.0	21.2	10.4	1387.1	918.3	20.0	9.3
45	1243.5	1179.3	21.2	7.6	1748.1	724.2	21.4	10.4	1403.8	927.4	20.3	9.2
46	1265.9	1182.7	21.4	7.5	1772.6	726.3	21.6	10.3	1420.3	936.4	20.5	9.1
47	1288.1	1185.8	21.6	7.5	1796.9	728.3	21.8	10.3	1436.6	945.2	20.7	9.0
48	1310.2	1188.6	21.8	7.4	1820.9	730.1	22.1	10.2	1452.7	953.9	20.9	8.9
49	1332.0	1191.1	22.0	7.3	1844.7	731.8	22.3	10.2	1468.6	962.4	21.1	8.8
50	1353.5	1193.4	22.2	7.3	1868.2	733.3	22.5	10.1	1484.3	970.8	21.3	8.7
51	1374.8	1195.5	22.4	7.2	1891.4	734.7	22.7	10.1	1498.7	980.2	21.6	8.6
52	1395.9	1197.3	22.6	7.2	1914.4	735.9	22.9	10.0	1514.9	987.4	21.8	8.5
53	1416.7	1198.9	22.8	7.1	1937.1	737.1	23.1	10.0	1530.1	995.4	22.0	8.4
54	1437.2	1200.3	23.0	7.0	1959.5	738.1	23.3	9.9	1545.8	1002.5	22.2	8.4
55	1457.4	1201.5	23.2	7.0	1981.6	739.0	23.5	9.9	1560.5	1010.2	22.3	8.3
56	1477.3	1202.6	23.4	6.9	2003.4	739.8	23.7	9.8	1574.4	1018.3	22.5	8.1
57	1497.0	1203.4	23.5	6.9	2024.9	740.5	23.9	9.8	1588.7	1025.6	22.7	8.0
58	1516.4	1204.0	23.7	6.8	2046.1	741.1	24.1	9.7	1602.9	1032.8	22.9	7.9
59	1535.4	1204.5	23.9	6.8	2067.0	741.6	24.3	9.7	1617.4	1039.3	23.1	7.8
60	1554.2	1204.9	24.0	6.7	2087.6	742.0	24.4	9.6	1630.3	1046.9	23.3	7.7
61	1572.7	1205.0	24.2	6.6	2107.9	742.3	24.6	9.6	1643.8	1053.8	23.4	7.6
62	1590.8	1205.1	24.3	6.6	2127.8	742.5	24.8	9.5	1656.4	1061.0	23.6	7.5
63	1608.7	1205.0	24.5	6.6	2147.5	742.7	25.0	9.4	1670.6	1066.4	23.8	7.4
64	1626.2	1204.7	24.6	6.5	2166.8	742.7	25.1	9.4	1683.5	1072.7	24.0	7.3
65	1643.5	1204.4	24.8	6.5	2185.8	742.7	25.3	9.3	1696.2	1078.9	24.1	7.2
66	1660.4	1203.9	24.9	6.4	2204.5	742.7	25.4	9.3	1708.7	1084.9	24.3	7.1
67	1677.0	1203.3	25.1	6.4	2222.9	742.6	25.6	9.2	1721.0	1090.8	24.4	7.0
68	1693.4	1202.7	25.2	6.4	2241.0	742.4	25.8	9.2	1733.1	1096.5	24.6	7.0
69	1709.4	1201.9	25.3	6.3	2258.7	742.1	25.9	9.1	1745.0	1102.1	24.7	6.9
70	1725.1	1201.0	25.5	6.3	2276.1	741.8	26.1	9.1	1756.7	1107.6	24.9	6.8
71	1740.6	1200.0	25.6	6.3	2293.3	741.5	26.2	9.0	1768.2	1112.9	25.0	6.7
72	1755.7	1199.0	25.7	6.3	2310.1	741.1	26.3	9.0	1779.5	1118.1	25.2	6.6
73	1769.7	1198.7	25.8	6.3	2326.6	740.6	26.5	9.0	1790.6	1123.2	25.3	6.5
74	1782.4	1199.3	25.9	6.2	2342.8	740.1	26.6	8.9	1801.4	1128.2	25.5	6.4
75	1794.9	1199.9	26.0	6.2	2358.7	739.6	26.7	8.9	1812.2	1133.0	25.6	6.3
76	1807.1	1200.3	26.2	6.2	2374.3	739.1	26.9	8.8	1822.7	1137.7	25.7	6.2
77	1819.1	1200.7	26.3	6.2	2389.6	738.5	27.0	8.8	1833.0	1142.3	25.9	6.2
78	1830.8	1200.9	26.4	6.2	2404.6	737.8	27.1	8.8	1843.1	1146.8	26.0	6.1
79					2419.3	737.1	27.2	8.7	1853.1	1151.1	26.1	6.0

Table A-32 (*continue*)

D[a]	Lab w/o Adj				Farm w/o Adj				Farm w Adj			
	Corn	SBM	P[b]	L[c]	Corn	SBM	P	L	Corn	SBM	P	L
80					2433.7	736.5	27.3	8.7	1862.8	1155.3	26.2	5.9
81					2447.9	735.7	27.5	8.7	1872.4	1159.5	26.3	5.9
82					2461.8	735.0	27.6	8.7	1881.8	1163.5	26.5	5.8
83					2475.3	734.2	27.7	8.7	1891.0	1167.4	26.6	5.7
84					2488.7	733.4	27.8	8.6	1900.1	1171.2	26.7	5.7
85					2501.7	732.6	27.9	8.6	1909.0	1174.9	26.8	5.6
86					2514.5	731.7	28.0	8.6	1917.7	1178.5	26.9	5.6
87					2527.0	730.9	28.1	8.6	1926.2	1182.0	27.0	5.5
88					2539.3	730.0	28.2	8.6	1934.6	1185.4	27.1	5.5
89					2551.3	729.1	28.3	8.6	1942.8	1188.8	27.2	5.4
90									1950.8	1192.0	27.3	5.4
91									1958.7	1195.1	27.4	5.3
92									1966.4	1198.2	27.5	5.3
93									1973.9	1201.2	27.6	5.3
94									1948.0	1236.1	27.7	5.0

[a] Each ingredient of ration composition was in grams per day.
[b] D = growing period, in day.
[c] P = Dicalcium phosphate in grams per day.
[d] L= Ground limestone in grams per day.

Table A- 33. Growth variable and daily ration composition[a] for the simulation models that included wheat as the energy supply feed ingredient for the CAFO of 4,000 pigs under P restriction when applicable land was adequate.

	Growth Variables				Ration Composition						Excretion		
D[b]	Wt[c]	PR[d]	TPIT[e]	TNIT[f]	FI[g]	Corn	SBM	Wheat	P[h]	L[i]	N[j]	P[k]	DM[l]
1	20.0	96.9	7.1	42.4	1091.4	620.1	449.3	0.0	13.0	9.0	28.2	3.5	103.9
2	20.6	98.9	7.2	43.5	1118.3	635.4	460.7	0.0	13.1	9.0	27.9	3.6	106.9
3	21.2	100.9	7.3	44.5	1145.6	652.0	471.2	0.0	13.3	9.1	29.4	3.7	110.0
4	21.8	102.8	7.5	45.5	1173.1	668.8	481.8	0.0	13.4	9.2	30.1	3.8	113.2
5	22.5	104.8	7.6	46.5	1201.0	685.7	492.5	0.0	13.6	9.2	30.8	3.9	116.5
6	23.1	106.8	7.8	47.7	1229.1	701.9	504.3	0.0	13.7	9.3	30.8	4.0	119.8
7	23.8	108.8	7.9	48.7	1257.5	719.1	515.3	0.0	13.9	9.3	31.6	4.0	123.1
8	24.5	110.7	8.1	49.8	1286.2	736.3	526.5	0.0	14.0	9.4	32.3	4.1	126.6
9	25.2	112.6	8.2	50.9	1315.1	753.8	537.7	0.0	14.2	9.4	33.1	4.2	130.0
10	25.9	114.3	8.5	52.0	1346.2	747.3	541.6	33.8	13.8	9.7	34.8	4.4	136.2
11	26.6	116.5	8.5	53.0	1373.4	789.6	559.8	0.0	14.4	9.5	35.5	4.4	137.2
12	27.3	118.4	8.7	54.1	1402.9	807.6	571.2	0.0	14.6	9.6	35.4	4.5	140.8
13	28.1	120.2	8.8	55.3	1432.5	824.7	583.4	0.0	14.7	9.6	36.2	4.6	144.5
14	28.8	122.1	9.0	56.4	1462.3	843.8	594.0	0.0	14.9	9.7	37.9	4.7	148.3
15	29.6	123.9	9.1	57.4	1492.2	862.6	604.9	0.0	15.0	9.7	38.7	4.8	152.1
16	30.4	125.0	9.7	58.7	1529.2	794.2	594.2	116.6	13.5	10.7	38.8	5.2	165.1
17	31.2	126.7	9.9	59.8	1559.8	803.7	603.4	128.4	13.5	10.8	39.6	5.3	169.9
18	32.0	128.2	10.1	60.9	1591.4	800.0	608.9	158.2	13.2	11.1	40.5	5.5	176.1
19	32.8	129.8	10.3	62.1	1622.1	808.6	617.9	171.3	13.2	11.2	41.3	5.7	181.0
20	33.7	131.7	10.4	63.2	1650.4	849.8	636.1	139.8	13.7	11.0	42.2	5.7	182.6
21	34.5	133.3	10.5	64.3	1681.1	860.2	645.6	150.5	13.7	11.1	43.0	5.8	187.4
22	35.4	134.9	10.7	65.2	1711.1	887.3	654.1	144.6	13.9	11.1	43.6	5.9	191.0
23	36.3	136.7	10.8	66.4	1740.1	915.9	670.9	128.0	14.3	11.0	44.5	5.9	193.8
24	37.1	138.3	10.9	67.2	1769.7	948.1	680.1	116.0	14.6	11.0	45.1	6.0	197.0
25	38.0	140.5	10.6	68.7	1792.1	1044.9	720.9	0.0	16.2	10.2	46.3	5.7	192.1
26	39.0	141.4	11.1	69.5	1828.4	1001.8	707.6	92.9	15.2	10.9	46.9	6.1	203.6
27	39.9	142.7	11.4	70.6	1859.9	999.1	714.1	120.6	15.3	10.8	47.8	6.3	209.9
28	40.8	144.8	11.0	71.8	1881.8	1103.1	751.8	0.0	16.6	10.3	48.7	6.0	204.7
29	41.8	146.2	11.2	72.8	1911.6	1122.2	762.4	0.0	16.7	10.3	50.7	6.1	209.0
30	42.7	146.5	12.2	73.8	1952.3	1016.7	735.3	173.6	15.9	10.8	51.6	6.7	226.8
31	43.7	147.7	12.5	74.9	1983.0	1015.9	741.3	199.1	16.0	10.7	52.5	6.9	233.0
32	44.7	148.8	12.8	76.0	2013.6	1012.9	747.0	226.9	16.1	10.7	52.2	7.0	239.4
33	45.7	149.8	13.1	77.1	2043.9	1011.4	752.4	253.2	16.3	10.7	53.1	7.2	245.6
34	46.7	150.8	13.4	78.1	2074.2	1007.4	756.9	282.8	16.4	10.7	53.7	7.4	252.2
35	47.7	151.7	13.7	79.0	2104.6	1001.0	758.3	318.1	16.5	10.7	55.4	7.5	259.1
36	48.7	154.7	12.3	80.0	2113.4	1251.7	833.5	0.0	18.1	10.0	55.1	6.7	238.7
37	49.8	153.6	14.3	81.1	2163.8	996.3	767.6	372.5	16.7	10.6	56.3	7.9	271.8

Table A-33 (*continue*)

	Growth Variables				Ration Composition						Excretion		
D[a]	Wt[c]	PR[d]	TPIT[e]	TNIT[f]	FI[g]	Corn	SBM	Wheat	P[h]	L[i]	N[j]	P[k]	DM[l]
38	50.8	154.1	14.9	82.2	2195.1	952.6	763.3	451.9	16.6	10.7	57.9	8.2	282.0
39	51.8	155.2	15.0	83.2	2221.5	983.2	777.6	433.2	16.9	10.6	57.9	8.2	284.8
40	52.9	155.7	15.5	84.2	2252.1	941.9	772.2	510.5	16.8	10.6	59.0	8.5	294.8
41	53.9	156.6	15.7	85.1	2278.9	957.7	780.8	513.0	17.0	10.6	60.4	8.6	299.1
42	55.0	160.6	13.2	85.7	2276.3	1356.0	891.3	0.0	19.5	9.6	60.1	7.2	263.9
43	56.1	161.0	13.8	86.8	2309.3	1304.2	882.1	94.0	19.4	9.6	62.5	7.6	275.4
44	57.2	147.3	22.4	88.1	2373.4	0.0	561.4	1787.6	11.6	12.9	63.5	12.3	403.6
45	58.2	163.0	13.6	88.3	2352.6	1406.6	916.5	0.0	20.2	9.3	62.3	7.5	276.0
46	59.3	163.7	13.8	89.2	2378.3	1423.7	925.0	0.0	20.4	9.2	63.0	7.6	280.2
47	60.4	164.5	13.9	90.1	2403.7	1440.6	933.3	0.0	20.6	9.1	63.7	7.6	284.3
48	61.6	165.2	14.1	90.9	2428.8	1457.2	941.7	0.0	20.9	9.0	64.2	7.7	288.4
49	62.7	150.4	23.7	92.3	2501.3	0.0	578.5	1898.1	12.1	12.6	67.3	13.0	431.5
50	63.8	150.9	23.9	93.0	2523.9	0.0	581.4	1917.7	12.2	12.6	67.5	13.1	436.5
51	64.8	151.3	24.1	93.7	2546.2	0.0	584.1	1937.2	12.3	12.6	68.1	13.2	441.4
52	65.8	151.8	24.3	94.4	2568.2	0.0	586.8	1956.5	12.4	12.5	69.2	13.4	446.3
53	66.9	152.2	24.5	95.1	2589.9	0.0	589.4	1975.6	12.5	12.5	69.8	13.5	451.2
54	67.9	152.6	24.7	95.7	2611.4	0.0	591.5	1994.9	12.6	12.4	72.3	13.6	456.0
55	69.0	153.0	24.9	96.4	2632.5	0.0	594.5	2012.9	12.7	12.4	70.9	13.7	460.8
56	70.1	153.4	25.1	97.1	2653.3	0.0	597.0	2031.2	12.8	12.3	71.0	13.8	465.5
57	71.1	153.7	25.3	97.7	2673.9	0.0	598.8	2050.0	12.8	12.3	74.1	13.9	470.2
58	72.2	154.1	25.5	98.3	2694.1	0.0	601.0	2067.9	12.9	12.2	74.7	14.0	474.8
59	73.3	154.4	25.7	98.9	2714.0	0.0	603.2	2085.6	13.0	12.2	75.3	14.1	479.4
60	74.4	154.7	25.9	99.5	2733.7	0.0	605.4	2103.1	13.1	12.1	75.8	14.2	483.9
61	75.5	154.9	26.1	100.1	2753.0	0.0	607.5	2120.2	13.2	12.1	76.4	14.3	488.3
62	76.5	155.2	26.3	100.6	2772.1	0.0	608.4	2138.4	13.3	12.0	76.4	14.4	492.8
63	77.6	171.7	16.0	101.4	2736.8	1633.6	1036.7	35.4	23.3	7.8	75.7	8.8	343.1
64	78.9	172.2	15.9	102.0	2754.1	1672.4	1050.4	0.0	23.7	7.6	74.2	8.7	343.8
65	80.1	172.3	16.2	102.8	2776.0	1660.7	1050.7	33.5	23.7	7.6	74.9	8.9	349.9
66	81.3	156.1	27.1	103.2	2851.3	0.0	618.3	2207.6	13.6	11.8	77.4	14.9	511.2
67	82.4	172.0	17.4	104.2	2824.9	1542.2	1026.3	225.5	23.2	7.7	76.4	9.5	371.2
68	83.7	172.2	17.5	104.8	2843.4	1554.2	1032.2	226.2	23.3	7.6	76.9	9.6	374.6
69	84.9	156.7	27.6	104.8	2906.5	0.0	623.0	2258.1	13.8	11.6	80.8	15.2	524.4
70	86.0	156.8	27.8	105.3	2922.9	0.0	625.3	2272.2	13.9	11.6	79.4	15.3	528.3
71	87.1	156.9	27.9	105.8	2939.2	0.0	626.1	2287.6	14.0	11.5	81.7	15.3	532.2
72	88.2	157.0	28.1	106.3	2955.2	0.0	627.6	2302.1	14.0	11.5	82.2	15.4	536.0
73	89.4	173.7	17.2	107.3	2915.3	1707.0	1081.9	95.0	24.6	6.9	81.3	9.5	379.2
74	90.6	157.2	28.4	107.3	2988.0	0.0	630.7	2331.8	14.2	11.4	82.6	15.6	544.0
75	91.7	173.9	17.4	108.3	2946.5	1728.8	1091.6	94.5	24.9	6.8	82.3	9.6	385.0
76	93.0	174.4	17.0	108.7	2955.8	1809.8	1114.0	0.0	25.4	6.5	82.6	9.3	380.6
77	94.3	157.4	28.9	108.6	3036.0	0.0	633.9	2376.5	14.4	11.2	85.6	15.9	555.7

Table A-33 (*continue*)

	Growth Variables				Ration Composition						Excretion		
D[a]	Wt[c]	PR[d]	TPIT[e]	TNIT[f]	FI[g]	Corn	SBM	Wheat	P[h]	L[i]	N[j]	P[k]	DM[l]
78	95.4	157.5	29.0	109.1	3050.1	0.0	635.9	2388.7	14.4	11.2	84.1	15.9	559.1
79	96.5	157.5	29.2	109.5	3064.2	0.0	635.9	2402.7	14.5	11.1	86.4	16.0	562.6
80	97.7	157.5	29.3	109.9	3077.8	0.0	638.0	2414.3	14.5	11.1	83.7	16.1	566.0
81	98.8	157.6	29.4	110.3	3091.3	0.0	639.0	2426.7	14.6	11.0	84.1	16.2	569.3
82	99.9	157.6	29.6	110.7	3104.5	0.0	639.5	2439.4	14.6	11.0	85.6	16.2	572.6
83	101.1	157.6	29.7	111.1	3117.5	0.0	640.7	2451.1	14.7	11.0	83.7	16.3	575.8
84	102.2	157.5	29.8	111.4	3130.2	0.0	641.2	2463.4	14.7	10.9	85.2	16.4	579.0
85	103.3	174.9	17.7	112.5	3074.8	1893.2	1149.3	0.0	26.4	5.9	86.3	9.7	403.3
86	104.6	174.9	17.7	112.9	3088.1	1902.6	1153.1	0.0	26.5	5.9	86.7	9.7	405.9
87	105.9	174.9	17.8	113.3	3101.1	1911.8	1156.8	0.0	26.7	5.8	87.1	9.8	408.4
88	107.2	174.9	17.9	113.7	3113.8	1921.2	1160.1	0.0	26.8	5.7	88.6	9.8	410.9
89	108.5	174.9	17.9	114.1	3126.2	1929.7	1163.9	0.0	26.9	5.7	87.9	9.9	413.4
90	109.8	157.3	30.6	113.6	3208.5	0.0	644.8	2537.9	15.0	10.7	90.0	16.8	599.0
91	110.9	158.4	30.1	113.9	3221.9	100.9	668.0	2426.8	15.7	10.5	89.6	16.5	593.7
92	112.0	157.2	30.8	114.2	3230.2	0.0	646.9	2557.5	15.1	10.7	87.3	16.9	604.5
93	113.2	157.1	30.9	114.5	3240.8	0.0	647.7	2567.2	15.2	10.7	87.1	17.0	607.2
94	114.3	157.0	31.0	114.7	3251.2	0.0	646.4	2579.0	15.2	10.7	91.8	17.0	610.0
95	115.5	174.4	18.6	116.1	3193.9	1930.1	1170.2	60.9	27.2	5.5	90.0	10.2	430.7
96	116.8	156.8	31.2	115.3	3272.5	0.0	647.1	2599.5	15.3	10.7	91.2	17.1	615.6
97	117.9	174.7	18.5	118.7	3207.9	1954.5	1220.7	0.0	27.6	5.1	89.5	10.2	430.2

[a] Each ingredient of ration composition was in grams per day.
[b] D = growing period, in day.
[c] Wt = body weight.
[d] PR = daily protein retention in gram per day.
[e] TPIT = Daily P intake, in gram per day.
[f] TNIT = Daily N intake, in gram per day.
[g] FI = Daily feed intake.
[h] P = Dicalcium phosphate.
[i] L= Ground limestone.
[j] N = daily N excretion per pig in grams per day.
[k] P = daily P excretion per pig in grams per day.
[l] DM = daily DM excretion per pig in grams per day.

Table A- 34. Daily growth levels for different animal capacities under P restriction when applicable land was adequate.

	4,000 pigs				10,000 pigs				16,000 pigs			
D[a]	Wt[b] kg	ADG[c] g	PR[d] g	PHR[e] g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
1	20.0	597.0	96.9	3.6	20.0	597.0	96.9	3.6	20.0	597.1	96.9	3.6
2	20.6	610.6	98.9	3.6	20.6	610.6	98.9	3.6	20.6	610.6	98.9	3.6
3	21.2	624.3	100.9	3.7	21.2	624.3	100.9	3.7	21.2	624.3	100.9	3.7
4	21.8	638.0	102.9	3.7	21.8	638.0	102.9	3.7	21.8	638.0	102.9	3.7
5	22.5	651.8	104.8	3.8	22.5	651.8	104.8	3.8	22.5	651.8	104.8	3.8
6	23.1	665.6	106.8	3.8	23.1	665.6	106.8	3.8	23.1	665.6	106.8	3.8
7	23.8	679.4	108.8	3.9	23.8	679.4	108.8	3.9	23.8	679.4	108.8	3.9
8	24.5	693.2	110.7	3.9	24.5	693.2	110.7	3.9	24.5	693.2	110.7	3.9
9	25.2	707.1	112.7	4.0	25.2	707.1	112.7	4.0	25.2	707.1	112.7	4.0
10	25.9	720.9	114.6	4.1	25.9	720.9	114.6	4.1	25.9	720.9	114.6	4.1
11	26.6	734.7	116.5	4.1	26.6	734.7	116.5	4.1	26.6	734.7	116.5	4.1
12	27.3	748.4	118.4	4.2	27.3	748.4	118.4	4.2	27.3	748.4	118.4	4.2
13	28.1	762.1	120.2	4.2	28.1	762.1	120.2	4.2	28.1	762.1	120.2	4.2
14	28.8	775.8	122.1	4.3	28.8	775.8	122.1	4.3	28.8	775.8	122.1	4.3
15	29.6	789.3	123.9	4.3	29.6	789.3	123.9	4.3	29.6	789.3	123.9	4.3
16	30.4	802.8	125.7	4.4	30.4	802.8	125.7	4.4	30.4	802.8	125.7	4.4
17	31.2	816.2	127.5	4.4	31.2	816.2	127.5	4.5	31.2	816.2	127.5	4.5
18	32.0	829.5	129.2	4.5	32.0	829.5	129.2	4.5	32.0	829.5	129.2	4.5
19	32.9	842.7	130.9	4.6	32.9	842.7	131.0	4.6	32.9	842.7	131.0	4.6
20	33.7	855.8	132.6	4.6	33.7	855.8	132.6	4.6	33.7	855.8	132.6	4.6
21	34.6	868.7	134.3	4.7	34.6	868.7	134.3	4.7	34.6	868.7	134.3	4.7
22	35.4	881.5	135.9	4.7	35.4	881.5	135.9	4.7	35.4	881.5	135.9	4.7
23	36.3	894.2	137.5	4.8	36.3	894.2	137.5	4.8	36.3	894.2	137.5	4.8
24	37.2	906.7	139.1	4.8	37.2	906.7	139.1	4.8	37.2	906.7	139.1	4.8
25	38.1	919.0	140.6	4.9	38.1	919.0	140.6	4.9	38.1	919.0	140.6	4.9
26	39.0	931.1	142.1	4.9	39.0	931.1	142.1	4.9	39.0	931.1	142.1	4.9
27	40.0	943.1	143.5	5.0	40.0	943.1	143.5	5.0	40.0	943.1	143.5	5.0
28	40.9	954.9	145.0	5.0	40.9	954.9	145.0	5.0	40.9	954.9	145.0	5.0
29	41.8	966.5	146.3	5.1	41.8	966.5	146.3	5.1	41.8	966.5	146.3	5.1
30	42.8	977.9	147.7	5.1	42.8	977.9	147.7	5.1	42.8	977.9	147.7	5.1
31	43.8	989.0	148.9	5.2	43.8	989.0	148.9	5.2	43.8	989.0	148.9	5.2
32	44.8	1000.0	150.2	5.2	44.8	1000.0	150.2	5.2	44.8	1000.0	150.2	5.2
33	45.8	1010.8	151.4	5.2	45.8	1010.8	151.4	5.2	45.8	1010.8	151.4	5.2
34	46.8	1021.3	152.6	5.3	46.8	1021.3	152.6	5.3	46.8	1021.3	152.6	5.3
35	47.8	1031.6	153.8	5.3	47.8	1031.6	153.8	5.3	47.8	1031.6	153.8	5.3
36	48.8	1041.7	154.9	5.3	48.8	1041.7	154.9	5.3	48.8	1041.7	154.9	5.3
37	49.9	1051.6	156.0	5.4	49.9	1051.6	156.0	5.4	49.9	1051.6	156.0	5.4
38	50.9	1061.3	157.0	5.4	50.9	1061.3	157.0	5.4	50.9	1061.3	157.0	5.4
39	52.0	1070.7	158.0	5.4	52.0	1070.7	158.0	5.4	52.0	1070.7	158.0	5.4

Table A-34. *(continue)*

D[a]	4,000 pigs				10,000 pigs				16,000 pigs			
	Wt[b] kg	ADG[c] g	PR[d] g	PHR[e] g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
40	53.1	1079.9	159.0	5.4	53.1	1079.9	159.0	5.4	53.1	1079.9	159.0	5.4
41	54.2	1088.9	159.9	5.5	54.2	1088.9	159.9	5.5	54.2	1088.9	159.9	5.5
42	55.2	1097.6	160.8	5.5	55.2	1097.6	160.8	5.5	55.2	1097.6	160.8	5.5
43	56.3	1106.1	161.7	5.5	56.3	1106.1	161.7	5.5	56.3	1106.1	161.7	5.5
44	57.4	1114.4	162.5	5.5	57.4	1114.4	162.5	5.5	57.4	1114.4	162.5	5.5
45	58.6	1122.4	163.3	5.5	58.6	1122.4	163.3	5.5	58.6	1122.4	163.3	5.5
46	59.7	1130.2	164.0	5.6	59.7	1130.2	164.0	5.6	59.7	1130.2	164.0	5.6
47	60.8	1137.8	164.8	5.6	60.8	1137.8	164.8	5.6	60.8	1137.8	164.8	5.6
48	61.9	1145.2	165.5	5.6	61.9	1145.2	165.5	5.6	61.9	1145.2	165.4	5.6
49	63.1	1152.3	166.1	5.6	63.1	1152.3	166.1	5.6	63.1	1152.3	166.1	5.6
50	64.2	1159.2	166.7	5.6	64.2	1159.2	166.7	5.6	64.2	1159.2	166.7	5.6
51	65.4	1165.9	167.3	5.7	65.4	1165.9	167.3	5.7	65.4	1165.9	167.3	5.7
52	66.6	1172.4	167.9	5.7	66.6	1172.4	167.9	5.7	66.6	1172.4	167.9	5.7
53	67.7	1178.6	168.5	5.7	67.7	1178.6	168.5	5.7	67.7	1178.6	168.5	5.7
54	68.9	1184.7	169.0	5.7	68.9	1184.7	169.0	5.7	68.9	1184.7	169.0	5.7
55	70.1	1190.5	169.5	5.7	70.1	1190.5	169.5	5.7	70.1	1190.5	169.5	5.7
56	71.3	1196.1	169.9	5.7	71.3	1196.1	169.9	5.7	71.3	1196.1	169.9	5.7
57	72.5	1201.5	170.4	5.7	72.5	1201.5	170.4	5.7	72.5	1201.5	170.4	5.7
58	73.7	1206.7	170.8	5.8	73.7	1206.7	170.8	5.8	73.7	1206.7	170.8	5.8
59	74.9	1211.7	171.2	5.8	74.9	1211.7	171.2	5.8	74.9	1211.7	171.2	5.8
60	76.1	1216.5	171.5	5.8	76.1	1216.5	171.5	5.8	76.1	1216.5	171.5	5.8
61	77.3	1221.2	171.9	5.8	77.3	1221.2	171.9	5.8	77.3	1221.2	171.9	5.8
62	78.6	1225.6	172.2	5.8	78.6	1225.6	172.2	5.8	78.6	1225.6	172.2	5.8
63	79.8	1229.8	172.5	5.8	79.8	1229.8	172.5	5.8	79.8	1229.8	172.5	5.8
64	81.0	1233.9	172.8	5.8	81.0	1233.9	172.8	5.8	81.0	1233.8	172.8	5.8
65	82.2	1237.7	173.0	5.8	82.2	1237.7	173.0	5.8	82.2	1237.7	173.0	5.8
66	83.5	1241.4	173.3	5.8	83.5	1241.4	173.3	5.8	83.5	1241.4	173.3	5.8
67	84.7	1244.9	173.5	5.8	84.7	1244.9	173.5	5.8	84.7	1244.9	173.5	5.8
68	86.0	1248.3	173.7	5.8	86.0	1248.3	173.7	5.8	86.0	1248.3	173.7	5.8
69	87.2	1251.5	173.9	5.8	87.2	1251.5	173.9	5.8	87.2	1251.4	173.9	5.8
70	88.5	1254.5	174.0	5.8	88.5	1254.5	174.0	5.8	88.5	1254.5	174.0	5.8
71	89.7	1257.3	174.2	5.8	89.7	1257.3	174.2	5.8	89.7	1257.3	174.2	5.8
72	91.0	1260.0	174.3	5.9	91.0	1260.0	174.3	5.9	91.0	1260.0	174.3	5.9
73	92.2	1262.6	174.5	5.9	92.2	1262.6	174.5	5.9	92.2	1262.6	174.5	5.9
74	93.5	1265.0	174.6	5.9	93.5	1265.0	174.6	5.9	93.5	1265.0	174.6	5.9
75	94.8	1267.2	174.7	5.9	94.8	1267.2	174.7	5.9	94.8	1267.2	174.7	5.9
76	96.0	1269.3	174.7	5.9	96.0	1269.3	174.7	5.9	96.0	1269.3	174.7	5.9
77	97.3	1271.3	174.8	5.9	97.3	1271.3	174.8	5.9	97.3	1271.3	174.8	5.9
78	98.6	1273.1	174.9	5.9	98.6	1273.1	174.9	5.9	98.6	1273.1	174.9	5.9
79	99.8	1274.8	174.9	5.9	99.8	1274.8	174.9	5.9	99.8	1274.8	174.9	5.9

Table A-34. (*continue*)

D[a]	4,000 pigs				10,000 pigs				16,000 pigs			
	Wt[b] kg	ADG[c] g	PR[d] g	PHR[e] g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
80	101.1	1276.4	175.0	5.9	101.1	1276.4	175.0	5.9	101.1	1276.4	175.0	5.9
81	102.4	1277.8	175.0	5.9	102.4	1277.8	175.0	5.9	102.4	1277.8	175.0	5.9
82	103.7	1279.1	175.0	5.9	103.7	1279.1	175.0	5.9	103.7	1279.1	175.0	5.9
83	105.0	1280.3	175.0	5.9	105.0	1280.3	175.0	5.9	105.0	1280.3	175.0	5.9
84	106.2	1281.4	175.0	5.9	106.2	1281.4	175.0	5.9	106.2	1281.4	175.0	5.9
85	107.5	1282.4	175.0	5.9	107.5	1282.4	175.0	5.9	107.5	1282.4	175.0	5.9
86	108.8	1283.2	175.0	5.9	108.8	1283.2	175.0	5.9	108.8	1283.2	175.0	5.9
87	110.1	1284.0	174.9	5.9	110.1	1284.0	174.9	5.9	110.1	1284.0	174.9	5.9
88	111.4	1284.6	174.9	5.8	111.4	1284.6	174.9	5.8	111.4	1284.6	174.9	5.8
89	112.6	1285.2	174.8	5.8	112.6	1285.2	174.8	5.8	112.6	1285.2	174.8	5.8
90	113.9	1285.6	174.8	5.8	113.9	1285.6	174.8	5.8	113.9	1285.6	174.8	5.8
91	115.2	1285.9	174.7	5.8	115.2	1285.9	174.7	5.8	115.2	1285.9	174.7	5.8
92	116.5	1286.2	174.7	5.8	116.5	1286.2	174.7	5.8	116.5	1286.2	174.7	5.8
93	117.8	1286.3	174.6	5.8	117.8	1286.3	174.6	5.8	117.8	1286.3	174.6	5.8
94	119.1	1286.6	174.7	5.8	119.1	1286.6	174.7	5.8	119.1	1286.6	174.7	5.8

[a] D = growing period, in day.
[b] Wt = pig body weight in kilograms.
[c] ADG= daily body weight gain in grams per day.
[d] PR= daily protein retention in grams per day.
[c] PHR= daily phosphorus retention in grams per day.

Table A- 35. Daily nutrient intake and excretion levels for different animal capacities under P restriction when applicable land was adequate.

	4,000 pigs					10,000 pigs					16,000 pigs				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
1	42.4	7.1	0.06	0.01	0.23	42.47	7.06	0.06	0.01	0.23	42.53	7.06	0.06	0.01	0.23
2	43.5	7.2	0.06	0.01	0.24	43.49	7.20	0.06	0.01	0.24	43.46	7.20	0.06	0.01	0.24
3	44.5	7.4	0.07	0.01	0.24	44.53	7.35	0.07	0.01	0.24	44.51	7.35	0.07	0.01	0.24
4	45.6	7.5	0.07	0.01	0.25	45.57	7.49	0.07	0.01	0.25	45.60	7.49	0.07	0.01	0.25
5	46.7	7.6	0.07	0.01	0.26	46.63	7.64	0.07	0.01	0.26	46.63	7.64	0.07	0.01	0.26
6	47.7	7.8	0.07	0.01	0.26	47.70	7.78	0.07	0.01	0.26	47.70	7.78	0.07	0.01	0.26
7	48.8	7.9	0.07	0.01	0.27	48.77	7.93	0.07	0.01	0.27	48.77	7.93	0.07	0.01	0.27
8	49.9	8.1	0.07	0.01	0.28	49.85	8.08	0.07	0.01	0.28	49.86	8.08	0.07	0.01	0.28
9	51.0	8.2	0.08	0.01	0.29	50.94	8.23	0.08	0.01	0.29	50.95	8.23	0.08	0.01	0.29
10	52.1	8.4	0.08	0.01	0.29	51.92	8.37	0.08	0.01	0.29	52.04	8.38	0.08	0.01	0.29
11	53.1	8.5	0.08	0.01	0.30	53.15	8.53	0.08	0.01	0.30	53.14	8.53	0.08	0.01	0.30
12	54.2	8.7	0.08	0.01	0.31	54.25	8.68	0.08	0.01	0.31	54.26	8.68	0.08	0.01	0.31
13	55.4	8.8	0.08	0.01	0.32	55.36	8.83	0.08	0.01	0.32	55.37	8.83	0.08	0.01	0.32
14	56.5	9.0	0.09	0.01	0.33	56.48	8.98	0.09	0.01	0.33	56.48	8.98	0.09	0.01	0.33
15	57.6	9.1	0.09	0.01	0.34	57.61	9.13	0.09	0.01	0.34	57.61	9.13	0.09	0.01	0.34
16	58.7	9.3	0.09	0.01	0.34	58.74	9.28	0.09	0.01	0.34	58.74	9.28	0.09	0.01	0.34
17	59.8	9.4	0.09	0.01	0.35	59.87	9.43	0.09	0.01	0.35	59.86	9.43	0.09	0.01	0.35
18	60.9	9.6	0.09	0.01	0.36	60.98	9.58	0.09	0.01	0.36	60.99	9.58	0.09	0.01	0.36
19	62.1	9.7	0.09	0.01	0.37	62.09	9.73	0.09	0.01	0.37	62.11	9.73	0.09	0.01	0.37
20	63.2	9.9	0.10	0.01	0.38	63.22	9.88	0.10	0.01	0.38	63.24	9.89	0.10	0.01	0.38
21	64.3	10.0	0.10	0.01	0.39	64.34	10.03	0.10	0.01	0.39	64.36	10.04	0.10	0.01	0.39
22	65.4	10.2	0.10	0.01	0.40	65.47	10.18	0.10	0.01	0.40	65.49	10.18	0.10	0.01	0.40
23	66.6	10.3	0.10	0.01	0.41	66.59	10.33	0.10	0.01	0.41	66.61	10.33	0.10	0.01	0.41
24	67.7	10.5	0.10	0.01	0.42	67.72	10.48	0.10	0.01	0.42	67.71	10.48	0.10	0.01	0.42
25	68.8	10.6	0.11	0.01	0.42	68.84	10.63	0.11	0.01	0.42	68.83	10.63	0.11	0.01	0.42
26	69.9	10.8	0.11	0.01	0.43	69.95	10.77	0.11	0.01	0.43	69.94	10.77	0.11	0.01	0.43
27	71.0	10.9	0.11	0.01	0.44	71.05	10.92	0.11	0.01	0.44	71.04	10.92	0.11	0.01	0.44
28	72.1	11.1	0.11	0.01	0.45	72.24	11.07	0.11	0.01	0.45	72.14	11.06	0.11	0.01	0.45
29	73.2	11.2	0.11	0.01	0.46	73.26	11.21	0.11	0.01	0.46	73.15	11.20	0.11	0.01	0.46
30	74.3	11.4	0.12	0.01	0.47	74.31	11.35	0.12	0.01	0.47	74.31	11.35	0.12	0.01	0.47
31	75.0	11.5	0.12	0.01	0.48	75.03	11.48	0.12	0.01	0.48	75.03	11.48	0.12	0.01	0.48
32	76.1	11.7	0.12	0.01	0.49	76.10	11.65	0.12	0.01	0.49	76.10	11.65	0.12	0.01	0.49
33	77.2	11.8	0.12	0.01	0.50	77.15	11.81	0.12	0.01	0.50	77.15	11.81	0.12	0.01	0.50
34	78.2	12.0	0.12	0.01	0.51	78.20	11.98	0.12	0.01	0.51	78.20	11.98	0.12	0.01	0.51
35	79.2	12.1	0.13	0.02	0.52	79.21	12.14	0.13	0.02	0.52	79.23	12.14	0.13	0.02	0.52
36	80.3	12.3	0.13	0.02	0.53	80.25	12.31	0.13	0.02	0.53	80.27	12.31	0.13	0.02	0.53
37	81.3	12.5	0.13	0.02	0.54	81.26	12.47	0.13	0.02	0.54	81.28	12.47	0.13	0.02	0.54
38	82.3	12.6	0.13	0.02	0.55	82.26	12.63	0.13	0.02	0.55	82.29	12.63	0.13	0.02	0.55

Table A-35 *(continue)*

	4,000 pigs					10,000 pigs					16,000 pigs				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
39	83.3	12.8	0.13	0.02	0.56	83.25	12.79	0.13	0.02	0.56	83.26	12.79	0.13	0.02	0.56
40	84.3	12.9	0.13	0.02	0.57	84.23	12.94	0.13	0.02	0.57	84.24	12.94	0.13	0.02	0.57
41	85.2	13.1	0.14	0.02	0.58	85.20	13.10	0.14	0.02	0.58	85.20	13.10	0.14	0.02	0.58
42	86.2	13.3	0.14	0.02	0.58	86.16	13.25	0.14	0.02	0.58	86.16	13.25	0.14	0.02	0.58
43	87.1	13.4	0.14	0.02	0.59	87.10	13.40	0.14	0.02	0.59	87.10	13.40	0.14	0.02	0.59
44	88.1	13.6	0.14	0.02	0.60	88.04	13.55	0.14	0.02	0.60	88.03	13.55	0.14	0.02	0.60
45	89.0	13.7	0.14	0.02	0.61	88.95	13.70	0.14	0.02	0.61	88.94	13.70	0.14	0.02	0.61
46	89.9	13.8	0.15	0.02	0.62	89.86	13.84	0.15	0.02	0.62	89.85	13.84	0.15	0.02	0.62
47	90.8	14.0	0.15	0.02	0.63	90.75	13.99	0.15	0.02	0.63	90.73	13.99	0.15	0.02	0.63
48	91.6	14.1	0.15	0.02	0.64	91.63	14.13	0.15	0.02	0.64	91.61	14.13	0.15	0.02	0.64
49	92.5	14.3	0.15	0.02	0.65	92.49	14.27	0.15	0.02	0.65	92.47	14.27	0.15	0.02	0.65
50	93.4	14.4	0.15	0.02	0.66	93.34	14.41	0.15	0.02	0.66	93.32	14.40	0.15	0.02	0.66
51	94.0	14.5	0.15	0.02	0.67	94.18	14.54	0.15	0.02	0.67	94.15	14.54	0.15	0.02	0.67
52	95.0	14.7	0.16	0.02	0.67	95.00	14.68	0.16	0.02	0.67	94.97	14.67	0.16	0.02	0.67
53	95.8	14.8	0.16	0.02	0.68	95.81	14.81	0.16	0.02	0.68	95.78	14.80	0.16	0.02	0.68
54	96.6	14.9	0.16	0.02	0.69	96.60	14.94	0.16	0.02	0.69	96.57	14.93	0.16	0.02	0.69
55	97.4	15.1	0.16	0.02	0.70	97.38	15.06	0.16	0.02	0.70	97.35	15.06	0.16	0.02	0.70
56	98.2	15.2	0.16	0.02	0.71	98.14	15.19	0.16	0.02	0.71	98.11	15.19	0.16	0.02	0.71
57	98.9	15.3	0.16	0.02	0.72	98.89	15.31	0.16	0.02	0.72	98.86	15.31	0.16	0.02	0.72
58	99.6	15.4	0.17	0.02	0.73	99.63	15.43	0.17	0.02	0.73	99.60	15.43	0.17	0.02	0.73
59	100.4	15.6	0.17	0.02	0.73	100.35	15.55	0.17	0.02	0.73	100.32	15.55	0.17	0.02	0.73
60	101.1	15.7	0.17	0.02	0.74	101.06	15.67	0.17	0.02	0.74	101.03	15.66	0.17	0.02	0.74
61	101.8	15.8	0.17	0.02	0.75	101.75	15.78	0.17	0.02	0.75	101.82	15.78	0.17	0.02	0.75
62	102.4	15.9	0.17	0.02	0.76	102.43	15.89	0.17	0.02	0.76	102.40	15.89	0.17	0.02	0.76
63	103.1	16.0	0.17	0.02	0.76	103.10	16.00	0.18	0.02	0.76	103.07	16.00	0.18	0.02	0.76
64	103.8	16.1	0.18	0.02	0.77	103.75	16.11	0.18	0.02	0.77	103.72	16.11	0.18	0.02	0.77
65	104.4	16.2	0.18	0.02	0.78	104.39	16.22	0.18	0.02	0.78	104.36	16.21	0.18	0.02	0.78
66	105.0	16.3	0.18	0.02	0.79	105.01	16.32	0.18	0.02	0.79	104.99	16.32	0.18	0.02	0.79
67	105.6	16.4	0.18	0.02	0.79	105.63	16.42	0.18	0.02	0.79	105.60	16.42	0.18	0.02	0.79
68	106.2	16.5	0.18	0.02	0.80	106.23	16.52	0.18	0.02	0.80	106.20	16.52	0.18	0.02	0.80
69	106.8	16.6	0.18	0.02	0.81	106.81	16.62	0.18	0.02	0.81	106.79	16.62	0.18	0.02	0.81
70	107.4	16.7	0.18	0.02	0.82	107.39	16.72	0.18	0.02	0.82	107.36	16.71	0.18	0.02	0.82
71	108.0	16.8	0.19	0.02	0.82	107.95	16.81	0.18	0.02	0.82	107.92	16.81	0.18	0.02	0.82
72	108.5	16.9	0.18	0.02	0.83	108.50	16.90	0.18	0.02	0.83	108.47	16.90	0.18	0.02	0.83
73	109.1	17.0	0.19	0.02	0.84	109.04	16.99	0.19	0.02	0.84	109.01	16.99	0.19	0.02	0.84
74	109.6	17.1	0.19	0.02	0.84	109.57	17.08	0.19	0.02	0.84	109.53	17.08	0.19	0.02	0.84
75	110.1	17.2	0.19	0.02	0.85	110.03	17.16	0.19	0.02	0.85	110.05	17.17	0.19	0.02	0.85
76	110.6	17.3	0.19	0.03	0.86	110.58	17.25	0.19	0.03	0.86	110.55	17.25	0.19	0.03	0.86
77	111.1	17.3	0.19	0.03	0.86	111.07	17.34	0.19	0.03	0.86	111.03	17.33	0.19	0.03	0.86

Table A-35. (*continue*)

D[a]	4,000 pigs					10,000 pigs					16,000 pigs				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
78	111.6	17.4	0.19	0.03	0.87	111.55	17.42	0.19	0.03	0.87	111.51	17.41	0.19	0.03	0.87
79	112.0	17.5	0.19	0.03	0.87	112.02	17.50	0.19	0.03	0.87	111.98	17.49	0.20	0.03	0.87
80	112.5	17.6	0.19	0.03	0.88	112.48	17.57	0.19	0.03	0.88	112.43	17.57	0.20	0.03	0.88
81	112.9	17.7	0.19	0.03	0.89	112.92	17.65	0.19	0.03	0.89	112.88	17.65	0.20	0.03	0.89
82	113.2	17.7	0.19	0.03	0.89	113.36	17.72	0.19	0.03	0.89	113.31	17.72	0.20	0.03	0.89
83	113.8	17.8	0.20	0.03	0.90	113.78	17.80	0.20	0.03	0.90	113.74	17.79	0.20	0.03	0.90
84	114.2	17.9	0.20	0.03	0.90	114.20	17.87	0.20	0.03	0.90	114.15	17.86	0.20	0.03	0.90
85	114.6	17.9	0.20	0.03	0.91	114.61	17.94	0.20	0.03	0.91	114.55	17.93	0.20	0.03	0.91
86	115.0	18.0	0.20	0.03	0.91	115.00	18.00	0.20	0.03	0.91	114.95	18.00	0.20	0.03	0.91
87	115.4	18.1	0.20	0.03	0.92	115.39	18.07	0.20	0.03	0.92	115.33	18.07	0.20	0.03	0.92
88	115.8	18.1	0.20	0.03	0.92	115.77	18.14	0.20	0.03	0.92	115.70	18.13	0.20	0.03	0.92
89	116.1	18.2	0.20	0.03	0.93	116.14	18.20	0.20	0.03	0.93	116.07	18.20	0.20	0.03	0.93
90	116.5	18.3	0.20	0.03	0.93	116.50	18.26	0.20	0.03	0.93	116.43	18.26	0.21	0.03	0.93
91	116.8	18.3	0.20	0.03	0.94	116.85	18.32	0.20	0.03	0.94	116.77	18.32	0.21	0.03	0.94
92	117.2	18.4	0.20	0.03	0.94	117.20	18.38	0.20	0.03	0.94	117.12	18.38	0.21	0.03	0.94
93	117.5	18.4	0.20	0.03	0.95	117.53	18.44	0.20	0.03	0.95	117.44	18.43	0.20	0.03	0.95
94	119.8	18.6	0.21	0.03	0.95	119.83	18.61	0.21	0.03	0.95	119.80	18.61	0.21	0.03	0.96

[a] D = growing period, in day.

Table A- 36. Daily ration composition[a] for different animal capacities under P restriction when applicable land was adequate.

	4,000 pigs					10,000 pigs					16,000 pigs				
D[b]	Corn	SBM	P[c]	L[d]	FI[e]	Corn	SBM	P	L	FI	Corn	SBM	P	L	FI
1	620	450	13.0	9.0	1091	619	451	13.0	9.0	1091	618	452	13.0	9.0	1091
2	635	461	13.1	9.0	1118	635	461	13.1	9.0	1118	635	461	13.1	9.0	1118
3	651	472	13.3	9.1	1146	651	472	13.3	9.1	1146	651	472	13.3	9.1	1146
4	667	483	13.4	9.1	1173	668	483	13.4	9.2	1173	667	484	13.4	9.1	1173
5	684	495	13.6	9.2	1201	684	494	13.6	9.2	1201	684	494	13.6	9.2	1201
6	701	506	13.7	9.3	1229	701	505	13.7	9.3	1229	701	505	13.7	9.3	1229
7	718	517	13.9	9.3	1258	718	516	13.9	9.3	1258	718	516	13.9	9.3	1258
8	735	528	14.0	9.4	1286	735	528	14.0	9.4	1286	735	528	14.0	9.4	1286
9	753	539	14.2	9.4	1315	753	539	14.2	9.4	1315	753	539	14.2	9.4	1315
10	770	550	14.3	9.5	1344	772	548	14.3	9.5	1344	770	550	14.3	9.5	1344
11	788	562	14.4	9.5	1373	788	562	14.4	9.5	1373	788	562	14.4	9.5	1373
12	806	573	14.6	9.6	1403	806	573	14.6	9.6	1403	806	573	14.6	9.6	1403
13	824	584	14.7	9.6	1433	824	585	14.7	9.6	1433	824	585	14.7	9.6	1433
14	842	596	14.9	9.7	1462	842	596	14.9	9.7	1462	842	596	14.9	9.7	1462
15	860	607	15.0	9.7	1492	860	608	15.0	9.7	1492	860	608	15.0	9.7	1492
16	879	619	15.1	9.8	1522	878	620	15.1	9.8	1522	878	620	15.1	9.8	1522
17	897	630	15.3	9.8	1552	896	631	15.3	9.8	1552	896	631	15.3	9.8	1552
18	915	642	15.4	9.9	1583	915	643	15.4	9.9	1583	915	643	15.4	9.9	1583
19	934	654	15.5	9.9	1613	933	654	15.5	9.9	1613	933	654	15.5	9.9	1613
20	952	665	15.6	10.0	1643	952	666	15.6	10.0	1643	951	666	15.6	10.0	1643
21	971	677	15.8	10.0	1673	970	677	15.8	10.0	1673	970	677	15.8	10.0	1673
22	989	688	15.9	10.0	1703	989	689	15.9	10.0	1703	989	689	15.9	10.0	1703
23	1008	700	16.0	10.1	1734	1007	700	16.0	10.1	1734	1007	700	16.0	10.1	1734
24	1026	711	16.1	10.1	1764	1026	712	16.1	10.1	1764	1026	712	16.1	10.1	1764
25	1045	723	16.2	10.2	1794	1044	723	16.2	10.2	1794	1044	723	16.2	10.2	1794
26	1063	734	16.3	10.2	1824	1063	735	16.3	10.2	1824	1063	735	16.3	10.2	1824
27	1082	745	16.5	10.2	1854	1081	746	16.5	10.2	1854	1082	746	16.5	10.2	1854
28	1100	757	16.6	10.3	1884	1098	759	16.6	10.3	1884	1100	757	16.6	10.3	1884
29	1119	768	16.7	10.3	1914	1118	769	16.7	10.3	1914	1120	767	16.7	10.3	1914
30	1137	779	16.8	10.3	1943	1137	779	16.8	10.3	1943	1137	779	16.8	10.3	1943
31	1161	785	16.9	10.4	1973	1161	784	16.9	10.4	1973	1161	784	16.9	10.4	1973
32	1179	795	17.2	10.3	2002	1179	795	17.2	10.3	2002	1179	795	17.2	10.3	2002
33	1198	806	17.4	10.2	2031	1198	806	17.4	10.2	2031	1198	806	17.4	10.2	2031
34	1216	817	17.7	10.2	2060	1216	817	17.7	10.2	2060	1216	817	17.7	10.2	2060
35	1234	827	17.9	10.1	2089	1234	827	17.9	10.1	2089	1234	827	17.9	10.1	2089
36	1251	837	18.2	10.0	2117	1252	837	18.2	10.0	2117	1251	838	18.2	10.0	2117
37	1269	848	18.4	9.9	2145	1269	847	18.4	9.9	2145	1269	848	18.4	9.9	2145
38	1287	858	18.6	9.9	2173	1287	858	18.6	9.9	2173	1287	858	18.6	9.9	2173
39	1304	868	18.9	9.8	2201	1305	868	18.9	9.8	2201	1305	868	18.9	9.8	2201

Table A-36. *(continue)*

	4,000 pigs					10,000 pigs					16,000 pigs				
D[a]	Corn	SBM	P[c]	L[d]	FI[e]	Corn	SBM	P	L	FI	Corn	SBM	P	L	FI
40	1322	878	19.1	9.7	2228	1322	877	19.1	9.7	2228	1322	877	19.1	9.7	2228
41	1339	887	19.4	9.6	2255	1339	887	19.4	9.6	2255	1339	887	19.4	9.6	2255
42	1356	897	19.6	9.5	2282	1356	897	19.6	9.5	2282	1356	897	19.6	9.5	2282
43	1373	907	19.8	9.4	2309	1373	906	19.8	9.4	2309	1373	906	19.8	9.4	2309
44	1390	916	20.0	9.3	2335	1390	916	20.0	9.3	2335	1390	915	20.0	9.3	2335
45	1406	925	20.3	9.2	2361	1407	925	20.3	9.2	2361	1407	925	20.3	9.2	2361
46	1423	934	20.5	9.1	2386	1423	934	20.5	9.2	2386	1423	934	20.5	9.2	2386
47	1439	943	20.7	9.1	2412	1439	943	20.7	9.1	2412	1440	942	20.7	9.1	2412
48	1455	952	20.9	9.0	2437	1455	951	20.9	9.0	2437	1456	951	20.9	9.0	2437
49	1471	960	21.1	8.9	2461	1471	960	21.1	8.9	2461	1472	960	21.1	8.9	2461
50	1487	969	21.3	8.8	2485	1487	968	21.3	8.8	2485	1487	968	21.3	8.8	2485
51	1505	975	21.6	8.7	2509	1502	977	21.6	8.7	2509	1503	976	21.6	8.7	2509
52	1517	985	21.8	8.6	2533	1518	985	21.8	8.6	2533	1518	984	21.8	8.6	2533
53	1533	993	22.0	8.5	2556	1533	993	22.0	8.5	2556	1533	992	22.0	8.5	2556
54	1548	1001	22.2	8.4	2579	1548	1001	22.2	8.4	2579	1548	1000	22.2	8.4	2579
55	1562	1009	22.3	8.3	2601	1562	1008	22.3	8.3	2601	1563	1008	22.3	8.3	2601
56	1576	1016	22.5	8.2	2623	1577	1016	22.5	8.2	2623	1577	1015	22.5	8.2	2623
57	1591	1023	22.7	8.1	2645	1591	1023	22.7	8.1	2645	1592	1023	22.7	8.1	2645
58	1605	1031	22.9	8.0	2667	1605	1030	22.9	8.0	2667	1606	1030	22.9	8.0	2667
59	1619	1038	23.1	7.9	2688	1619	1037	23.1	7.9	2688	1620	1037	23.1	7.9	2688
60	1633	1045	23.3	7.8	2708	1633	1044	23.3	7.8	2708	1633	1044	23.3	7.8	2708
61	1646	1051	23.4	7.7	2729	1647	1051	23.4	7.7	2729	1645	1052	23.4	7.6	2729
62	1660	1058	23.6	7.6	2749	1660	1058	23.6	7.6	2749	1660	1057	23.6	7.6	2749
63	1673	1064	23.8	7.5	2768	1673	1064	23.8	7.5	2768	1673	1064	23.8	7.5	2768
64	1686	1071	24.0	7.4	2788	1686	1071	24.0	7.4	2788	1686	1070	24.0	7.4	2788
65	1698	1077	24.1	7.3	2807	1698	1077	24.1	7.3	2807	1699	1076	24.1	7.3	2807
66	1711	1083	24.3	7.2	2825	1711	1083	24.3	7.2	2825	1711	1082	24.3	7.2	2825
67	1723	1089	24.4	7.1	2843	1723	1089	24.4	7.1	2843	1724	1088	24.4	7.1	2843
68	1735	1095	24.6	7.0	2861	1735	1095	24.6	7.0	2861	1736	1094	24.6	7.0	2861
69	1747	1100	24.7	6.9	2879	1747	1100	24.7	6.9	2879	1747	1100	24.7	6.9	2879
70	1758	1106	24.9	6.8	2896	1759	1106	24.9	6.8	2896	1759	1105	24.9	6.8	2896
71	1770	1111	25.0	6.7	2913	1770	1111	25.0	6.7	2913	1771	1111	25.0	6.7	2913
72	1781	1117	25.2	6.6	2929	1781	1116	25.2	6.6	2929	1782	1116	25.2	6.6	2929
73	1792	1122	25.3	6.5	2946	1792	1122	25.3	6.5	2946	1793	1121	25.3	6.5	2946
74	1803	1127	25.5	6.4	2962	1803	1127	25.5	6.4	2962	1804	1126	25.5	6.4	2962
75	1814	1132	25.6	6.3	2977	1815	1131	25.6	6.3	2977	1814	1131	25.6	6.3	2977
76	1824	1136	25.7	6.3	2992	1824	1136	25.7	6.3	2992	1825	1136	25.7	6.3	2992
77	1834	1141	25.9	6.2	3007	1834	1141	25.9	6.2	3007	1835	1140	25.9	6.2	3007
78	1844	1146	26.0	6.1	3022	1844	1146	26.0	6.1	3022	1845	1145	26.0	6.1	3022
79	1854	1150	26.1	6.0	3036	1854	1150	26.1	6.0	3036	1855	1149	26.1	6.0	3036

Table A-36. (*continue*)

D[a]	4,000 pigs					10,000 pigs					16,000 pigs				
	Corn	SBM	P[c]	L[d]	FI[e]	Corn	SBM	P	L	FI	Corn	SBM	P	L	FI
80	1864	1154	26.2	5.9	3050	1864	1154	26.2	5.9	3050	1865	1154	26.2	6.0	3051
81	1873	1159	26.3	5.9	3064	1874	1159	26.3	5.9	3064	1874	1158	26.3	5.9	3064
82	1885	1160	26.5	5.8	3078	1883	1163	26.5	5.8	3078	1884	1162	26.5	5.8	3078
83	1892	1167	26.6	5.7	3091	1892	1167	26.6	5.7	3091	1893	1166	26.6	5.7	3091
84	1901	1171	26.7	5.7	3104	1901	1171	26.7	5.7	3104	1902	1170	26.7	5.7	3104
85	1910	1174	26.8	5.6	3116	1910	1174	26.8	5.6	3116	1911	1173	26.8	5.6	3116
86	1918	1178	26.9	5.6	3129	1918	1178	26.9	5.6	3129	1919	1177	26.9	5.6	3129
87	1927	1182	27.0	5.5	3141	1927	1182	27.0	5.5	3141	1928	1181	27.0	5.5	3141
88	1935	1185	27.1	5.5	3153	1935	1185	27.1	5.5	3153	1936	1184	27.1	5.5	3153
89	1943	1189	27.2	5.4	3164	1943	1189	27.2	5.4	3164	1944	1188	27.2	5.4	3164
90	1951	1192	27.3	5.4	3176	1951	1192	27.3	5.4	3176	1952	1191	27.3	5.4	3176
91	1959	1195	27.4	5.3	3187	1958	1195	27.4	5.3	3186	1960	1194	27.4	5.3	3187
92	1966	1198	27.5	5.3	3197	1966	1199	27.5	5.3	3197	1967	1197	27.5	5.3	3197
93	1974	1201	27.6	5.3	3208	1973	1202	27.6	5.3	3208	1975	1200	27.6	5.3	3208
94	1948	1237	27.7	5.0	3217	1948	1236	27.7	5.0	3217	1948	1236	27.7	5.0	3217

[a] Each ingredient of ration composition was in grams per day.
[b] D = growing period, in day.
[c] P = Dicalcium phosphate in grams per day.
[d] L= Ground limestone in grams per day.
[e] FI = Daily feed intake per pig in grams per day.

Table A- 37. Daily growth levels for different animal capacities under P restriction when applicable land was 834 acres.

	4,000 pigs				10,000 pigs				16,000 pigs			
D[a]	Wt[b] kg	ADG[c] g	PR[d] g	PHR[e] g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
1	20.00	597.05	96.91	3.55	20.0	597.5	96.9	3.8	20.0	593.8	96.2	3.8
2	20.60	610.65	98.89	3.61	20.6	611.1	98.9	3.8	20.6	610.1	98.6	3.8
3	21.21	624.31	100.88	3.66	21.2	624.8	100.9	3.9	21.2	621.0	100.2	3.9
4	21.83	638.04	102.86	3.72	21.8	638.0	102.8	3.7	21.8	637.4	102.6	3.7
5	22.47	651.80	104.83	3.77	22.5	652.3	104.9	4.0	22.5	648.4	104.1	4.0
6	23.12	665.60	106.80	3.83	23.1	666.1	106.8	4.1	23.1	664.9	106.5	4.1
7	23.79	679.42	108.76	3.89	23.8	679.3	108.7	3.9	23.8	678.7	108.5	3.9
8	24.47	693.24	110.71	3.94	24.5	693.6	110.7	3.94	24.5	692.5	110.4	4.2
9	25.16	707.07	112.65	4.00	25.2	707.5	112.6	4.00	25.2	706.3	112.3	4.3
10	25.87	720.88	114.57	4.06	25.9	721.3	114.6	4.06	25.9	717.3	113.8	4.4
11	26.59	734.67	116.48	4.11	26.6	735.0	116.5	4.11	26.6	733.8	116.1	4.5
12	27.32	748.42	118.37	4.17	27.3	748.8	118.3	4.17	27.3	744.8	117.6	4.6
13	28.07	762.12	120.24	4.22	28.1	762.4	120.2	4.22	28.1	758.4	119.5	4.7
14	28.83	775.76	122.08	4.28	28.8	776.1	122.0	4.28	28.8	774.7	121.7	4.8
15	29.61	789.34	123.91	4.33	29.6	789.6	123.9	4.33	29.6	788.3	123.5	4.9
16	30.40	802.83	125.71	4.39	30.4	802.8	125.6	4.39	30.4	799.1	124.9	4.4
17	31.20	816.23	127.48	4.45	31.2	816.2	127.4	4.45	31.2	812.4	126.7	4.4
18	32.02	829.53	129.23	4.50	32.0	829.5	129.2	4.50	32.0	825.7	128.4	4.5
19	32.85	842.72	130.95	4.55	32.9	842.7	130.9	4.55	32.8	841.5	130.5	4.6
20	33.69	855.79	132.63	4.61	33.7	855.7	132.6	4.61	33.7	854.5	132.2	4.6
21	34.55	868.72	134.29	4.66	34.6	868.8	134.2	4.66	34.5	864.8	133.5	5.5
22	35.41	881.52	135.92	4.71	35.4	881.4	135.8	4.71	35.4	877.5	135.1	4.7
23	36.30	894.17	137.51	4.77	36.3	894.1	137.4	4.77	36.3	890.1	136.7	4.8
24	37.19	906.66	139.07	4.82	37.2	906.7	139.0	4.82	37.1	905.2	138.6	5.8
25	38.10	918.98	140.59	4.87	38.1	919.0	140.5	4.87	38.0	917.6	140.1	5.9
26	39.02	931.14	142.08	4.92	39.0	931.1	142.0	4.92	39.0	927.1	141.2	6.0
27	39.95	943.11	143.54	4.97	40.0	943.0	143.5	4.97	39.9	939.0	142.7	5.0
28	40.89	954.90	144.95	5.02	40.9	954.8	144.9	5.02	40.8	953.4	144.5	5.0
29	41.84	966.50	146.33	5.07	41.9	966.4	146.3	5.07	41.8	962.4	145.5	5.1
30	42.81	977.90	147.68	5.12	42.8	977.8	147.6	5.12	42.7	973.8	146.8	5.1
31	43.79	989.03	148.94	5.16	43.8	989.0	148.9	5.16	43.7	987.5	148.5	5.2
32	44.78	1000.00	150.21	5.19	44.8	999.9	150.1	5.19	44.7	998.5	149.7	5.2
33	45.78	1010.76	151.43	5.23	45.8	1010.7	151.4	5.23	45.7	1006.7	150.6	6.6
34	46.79	1021.30	152.62	5.26	46.8	1021.2	152.5	5.26	46.7	1017.3	151.8	5.4
35	47.81	1031.62	153.77	5.29	47.8	1031.5	153.7	5.29	47.7	1030.1	153.3	5.4
36	48.84	1041.73	154.89	5.32	48.9	1041.6	154.8	5.32	48.8	1037.7	154.1	5.5
37	49.88	1051.60	155.96	5.35	49.9	1051.5	155.9	5.35	49.8	1050.0	155.4	7.0
38	50.94	1061.26	157.00	5.37	50.9	1061.1	156.9	5.37	50.8	1059.7	156.5	5.7

Table A-37. ***(continue)***

	4,000 pigs				10,000 pigs				16,000 pigs			
D[a]	Wt[b], kg	ADG[c], g	PR[d], g	PHR[e], g	Wt kg	ADG g	PR g	PHRg	Wt kg	ADG g	PRg	PHRg
39	52.00	1070.68	158.00	5.40	52.0	1070.6	157.9	5.40	51.9	1069.1	157.5	5.7
40	53.07	1079.88	158.97	5.43	53.1	1079.8	158.9	5.43	53.0	1078.3	158.4	7.3
41	54.15	1088.84	159.90	5.45	54.2	1088.7	159.8	5.45	54.1	1087.3	159.4	5.9
42	55.24	1097.58	160.79	5.48	55.2	1097.4	160.7	5.48	55.1	1096.1	160.3	5.9
43	56.33	1106.09	161.65	5.50	56.3	1106.0	161.6	5.50	56.2	1104.6	161.1	6.0
44	57.44	1114.36	162.48	5.52	57.4	1114.2	162.4	5.52	57.3	1112.9	161.9	6.1
45	58.55	1122.41	163.27	5.54	58.6	1122.3	163.2	5.54	58.5	1120.9	162.7	6.1
46	59.68	1130.23	164.03	5.56	59.7	1130.1	163.9	5.56	59.6	1128.7	163.5	6.2
47	60.81	1137.81	164.75	5.58	60.8	1137.7	164.6	5.58	60.7	1134.3	164.0	6.3
48	61.94	1145.17	165.44	5.60	62.0	1145.0	165.3	5.60	61.8	1143.7	164.9	6.3
49	63.09	1152.31	166.10	5.62	63.1	1152.2	166.0	5.62	63.0	1150.9	165.6	6.4
50	64.24	1159.22	166.74	5.64	64.2	1159.1	166.6	5.64	64.1	1157.8	166.2	6.5
51	65.40	1165.91	167.34	5.66	65.4	1165.8	167.2	5.66	65.3	1164.5	166.8	6.5
52	66.57	1172.38	167.91	5.67	66.6	1172.2	167.8	5.67	66.5	1171.0	167.4	6.6
53	67.74	1178.63	168.45	5.69	67.7	1178.5	168.3	5.69	67.6	1177.2	167.9	6.6
54	68.92	1184.67	168.97	5.70	68.9	1184.5	168.9	5.70	68.8	1181.4	168.2	6.7
55	70.10	1190.50	169.45	5.72	70.1	1190.3	169.3	5.72	70.0	1187.3	168.7	6.8
56	71.29	1196.11	169.91	5.73	71.3	1196.0	169.8	5.73	71.2	1192.9	169.2	6.8
57	72.49	1201.52	170.35	5.74	72.5	1201.4	170.2	5.74	72.4	1198.4	169.6	8.6
58	73.69	1206.72	170.76	5.75	73.7	1206.6	170.6	5.75	73.6	1203.6	170.0	6.9
59	74.90	1211.73	171.15	5.76	74.9	1211.6	171.0	5.76	74.8	1208.7	170.4	7.0
60	76.11	1216.53	171.51	5.77	76.1	1216.4	171.4	5.77	76.0	1213.5	170.8	7.0
61	77.33	1221.14	171.86	5.78	77.3	1221.0	171.7	5.78	77.2	1218.2	171.1	7.1
62	78.55	1225.57	172.18	5.79	78.6	1225.4	172.1	5.79	78.4	1210.4	169.9	7.1
63	79.77	1229.80	172.47	5.80	79.8	1229.6	172.4	5.80	79.6	1211.1	169.7	7.2
64	81.00	1233.85	172.75	5.81	81.0	1233.7	172.6	5.81	80.8	1212.9	169.7	7.2
65	82.24	1237.71	173.01	5.81	82.2	1237.5	172.9	5.81	82.0	1213.9	169.6	7.3
66	83.47	1241.40	173.25	5.82	83.5	1241.2	173.1	5.82	83.3	1214.7	169.5	7.3
67	84.72	1244.92	173.47	5.83	84.7	1244.8	173.4	5.83	84.5	1215.1	169.3	7.4
68	85.96	1248.27	173.68	5.83	86.0	1248.1	173.6	5.83	85.7	1219.0	169.6	7.4
69	87.21	1251.44	173.86	5.84	87.2	1251.3	173.7	5.84	86.9	1218.1	169.3	7.5
70	88.46	1254.46	174.03	5.84	88.5	1254.3	173.9	5.84	88.1	1216.9	168.9	7.5
71	89.71	1257.32	174.19	5.84	89.7	1257.1	174.1	5.84	89.3	1215.3	168.5	7.5
72	90.97	1260.01	174.33	5.85	91.0	1259.8	174.2	5.85	90.6	1213.5	168.1	7.6
73	92.23	1262.56	174.45	5.85	92.2	1262.4	174.3	5.85	91.8	1211.9	167.7	7.6
74	93.49	1264.96	174.56	5.85	93.5	1264.8	174.4	5.85	93.0	1209.4	167.2	7.7
75	94.76	1267.20	174.66	5.85	94.8	1267.0	174.5	5.85	94.2	1207.3	166.8	7.7
76	96.03	1269.31	174.74	5.86	96.0	1269.1	174.6	5.86	95.4	1204.9	166.3	7.7
77	97.30	1271.28	174.81	5.86	97.3	1271.1	174.7	5.86	96.6	1204.1	166.1	7.8
78	98.57	1273.11	174.87	5.86	98.6	1272.9	174.7	5.86	97.8	1203.7	165.9	7.8

Table A-37. (*continue*)

	4,000 pigs				10,000 pigs				16,000 pigs			
D[a]	Wt[b], kg	ADG[c], g	PR[d], g	PHR[e], g	Wt kg	ADG g	PR g	PHR g	Wt kg	ADG g	PR g	PHR g
79	99.84	1274.81	174.91	5.86	99.8	1274.6	174.8	5.86	99.0	1205.2	165.9	7.8
80	101.11	1276.37	174.95	5.86	101.1	1276.2	174.8	5.86	100.2	1206.5	165.9	9.9
81	102.39	1277.82	174.97	5.86	102.4	1277.7	174.9	5.86	101.4	1207.8	165.9	9.9
82	103.67	1279.13	174.99	5.85	103.7	1279.0	174.9	5.85	102.6	1208.9	166.0	10.0
83	104.95	1280.33	174.99	5.85	104.9	1280.2	174.9	5.85	103.8	1209.9	166.0	10.0
84	106.23	1281.41	174.99	5.85	106.2	1281.3	174.9	5.85	105.0	1210.9	165.9	10.0
85	107.51	1282.38	174.98	5.85	107.5	1282.2	174.9	5.85	106.3	1211.7	165.9	10.1
86	108.79	1283.25	174.97	5.85	108.8	1283.1	174.8	5.85	107.5	1212.4	165.9	10.1
87	110.08	1283.98	174.92	5.85	110.1	1283.8	174.8	5.85	108.7	1213.1	165.9	10.2
88	111.36	1284.62	174.88	5.84	111.4	1284.5	174.8	5.84	109.9	1213.6	165.8	10.2
89	112.64	1285.15	174.84	5.84	112.6	1285.0	174.7	5.84	111.1	1214.1	165.8	10.2
90	113.93	1285.59	174.78	5.84	113.9	1285.4	174.7	5.84	112.3	1214.5	165.7	10.3
91	115.21	1285.93	174.72	5.83	115.2	1285.8	174.6	5.83	113.5	1214.8	165.7	10.3
92	116.50	1286.17	174.65	5.83	116.5	1286.0	174.5	5.83	114.8	1215.0	165.6	10.3
93	117.79	1286.32	174.58	5.82	117.8	1286.2	174.5	5.82	116.0	1215.1	165.6	10.4
94	119.07	1286.60	174.71	5.82	119.1	1286.5	174.6	5.82	117.2	1215.1	165.5	10.5
95									118.4	1215.1	165.4	10.4
96									119.6	1286.2	166.3	10.4

[a] D = growing period, in day.
[b] Wt = pig body weight in kilograms.
[c] ADG= daily body weight gain in grams per day.
[d] PR= daily protein retention in grams per day.
[c] PHR= daily phosphorus retention in grams per day.

Table A- 38. Daily nutrient intake and excretion levels for different animal capacities under P restriction when applicable land was 834 acres.

	4,000 pigs					10,000 pigs					16,000 pigs				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
1	42.51	7.06	0.06	0.01	0.23	42.0	6.5	0.1	0.0	0.2	40.8	9.7	0.06	0.004	0.23
2	43.53	7.20	0.06	0.01	0.24	43.0	6.6	0.1	0.0	0.2	41.7	7.1	0.06	0.008	0.24
3	44.57	7.35	0.07	0.01	0.24	44.0	6.8	0.1	0.0	0.2	42.8	10.0	0.06	0.004	0.24
4	45.61	7.49	0.07	0.01	0.25	45.1	7.5	0.1	0.0	0.2	43.7	7.4	0.06	0.008	0.25
5	46.66	7.64	0.07	0.01	0.26	46.1	7.1	0.1	0.0	0.3	44.8	10.4	0.07	0.005	0.26
6	47.72	7.78	0.07	0.01	0.26	47.2	7.2	0.1	0.0	0.3	45.8	7.7	0.07	0.009	0.26
7	48.80	7.93	0.07	0.01	0.27	48.2	7.9	0.1	0.0	0.3	46.8	7.9	0.07	0.009	0.27
8	49.88	8.08	0.07	0.01	0.28	49.1	7.5	0.1	0.0	0.3	47.8	8.0	0.07	0.009	0.28
9	50.95	8.23	0.08	0.01	0.29	50.2	7.7	0.1	0.0	0.3	48.9	8.2	0.07	0.009	0.29
10	52.04	8.38	0.08	0.01	0.29	51.3	7.8	0.1	0.0	0.3	50.0	11.2	0.07	0.006	0.29
11	53.15	8.53	0.08	0.01	0.30	52.4	8.0	0.1	0.0	0.3	51.0	8.4	0.07	0.010	0.30
12	54.26	8.68	0.08	0.01	0.31	53.4	8.2	0.1	0.0	0.3	52.1	11.5	0.08	0.006	0.31
13	55.37	8.83	0.08	0.01	0.32	54.5	8.3	0.1	0.0	0.3	53.2	11.7	0.08	0.006	0.32
14	56.48	8.98	0.09	0.01	0.33	55.7	8.5	0.1	0.0	0.3	54.2	8.9	0.08	0.010	0.33
15	57.60	9.13	0.09	0.01	0.34	56.8	8.7	0.1	0.0	0.3	55.2	9.0	0.08	0.010	0.34
16	58.72	9.28	0.09	0.01	0.34	58.1	9.3	0.1	0.0	0.3	56.4	12.2	0.08	0.006	0.34
17	59.84	9.43	0.09	0.01	0.35	59.2	9.4	0.1	0.0	0.4	57.5	12.3	0.09	0.007	0.35
18	60.97	9.58	0.09	0.01	0.36	60.3	9.6	0.1	0.0	0.4	58.6	12.5	0.09	0.007	0.36
19	62.09	9.73	0.09	0.01	0.37	61.5	9.7	0.1	0.0	0.4	59.6	9.6	0.09	0.011	0.37
20	63.21	9.88	0.10	0.01	0.38	62.6	9.9	0.1	0.0	0.4	60.7	9.8	0.09	0.011	0.38
21	64.34	10.03	0.10	0.01	0.39	63.4	9.7	0.1	0.0	0.4	61.8	13.0	0.09	0.007	0.39
22	65.46	10.18	0.10	0.01	0.40	64.8	10.2	0.1	0.0	0.4	62.9	13.1	0.10	0.008	0.40
23	66.58	10.33	0.10	0.01	0.41	65.9	10.3	0.1	0.0	0.4	64.0	13.3	0.10	0.008	0.41
24	67.69	10.48	0.10	0.01	0.42	66.7	10.2	0.1	0.0	0.4	65.0	10.4	0.10	0.012	0.41
25	68.80	10.63	0.11	0.01	0.42	67.8	10.4	0.1	0.0	0.4	66.0	10.5	0.10	0.012	0.42
26	69.91	10.77	0.11	0.01	0.43	68.9	10.6	0.1	0.0	0.4	67.2	13.8	0.10	0.008	0.43
27	71.02	10.92	0.11	0.01	0.44	70.3	10.9	0.1	0.0	0.4	68.3	13.9	0.10	0.008	0.44
28	72.11	11.06	0.11	0.01	0.45	71.4	11.0	0.1	0.0	0.5	69.2	10.9	0.11	0.013	0.45
29	73.19	11.21	0.11	0.01	0.46	72.5	11.2	0.1	0.0	0.5	70.4	14.2	0.11	0.009	0.46
30	74.28	11.35	0.12	0.01	0.47	73.5	11.3	0.1	0.0	0.5	71.4	14.4	0.11	0.009	0.47
31	75.01	11.48	0.12	0.01	0.48	74.6	11.5	0.1	0.0	0.5	72.3	11.4	0.11	0.014	0.48
32	76.08	11.65	0.12	0.01	0.49	75.3	11.6	0.1	0.0	0.5	73.3	11.5	0.11	0.014	0.49
33	77.14	11.81	0.12	0.01	0.50	76.4	11.8	0.1	0.0	0.5	74.5	14.8	0.12	0.009	0.50
34	78.17	11.98	0.12	0.01	0.51	77.4	11.9	0.1	0.0	0.5	75.5	15.0	0.12	0.010	0.51
35	79.21	12.14	0.13	0.02	0.52	78.4	12.1	0.1	0.0	0.5	76.1	12.0	0.12	0.014	0.52
36	80.23	12.31	0.13	0.02	0.53	79.4	12.3	0.1	0.0	0.5	77.5	15.3	0.12	0.010	0.53
37	81.25	12.47	0.13	0.02	0.54	80.5	12.4	0.1	0.0	0.5	78.0	12.3	0.12	0.015	0.54

Table A-38. ***(continue)***

	4,000 pigs					10,000 pigs					16,000 pigs				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
38	82.25	12.63	0.13	0.02	0.55	81.4	12.6	0.1	0.0	0.5	79.0	12.4	0.12	0.015	0.55
39	83.24	12.79	0.13	0.02	0.56	82.4	12.7	0.1	0.0	0.6	80.0	12.6	0.13	0.015	0.56
40	84.22	12.94	0.13	0.02	0.57	83.4	12.9	0.1	0.0	0.6	80.9	12.7	0.13	0.015	0.57
41	85.19	13.10	0.14	0.02	0.58	84.4	13.1	0.1	0.0	0.6	81.8	12.9	0.13	0.016	0.57
42	86.15	13.25	0.14	0.02	0.58	85.3	13.2	0.1	0.0	0.6	82.7	13.0	0.13	0.016	0.58
43	87.09	13.40	0.14	0.02	0.59	86.2	13.4	0.1	0.0	0.6	83.7	13.2	0.13	0.016	0.59
44	88.02	13.55	0.14	0.02	0.60	87.2	13.5	0.1	0.0	0.6	84.5	13.3	0.13	0.016	0.60
45	88.94	13.70	0.14	0.02	0.61	88.1	13.7	0.1	0.0	0.6	85.4	13.5	0.14	0.016	0.61
46	89.85	13.84	0.15	0.02	0.62	89.0	13.8	0.1	0.0	0.6	86.3	13.6	0.14	0.017	0.62
47	90.73	13.99	0.15	0.02	0.63	89.8	13.9	0.1	0.0	0.6	87.6	16.6	0.14	0.012	0.63
48	91.61	14.13	0.15	0.02	0.64	90.7	14.1	0.1	0.0	0.6	88.0	13.9	0.14	0.017	0.64
49	92.47	14.27	0.15	0.02	0.65	91.6	14.2	0.1	0.0	0.6	88.8	14.1	0.14	0.017	0.65
50	93.32	14.40	0.15	0.02	0.66	92.4	14.4	0.2	0.0	0.7	89.6	14.2	0.14	0.017	0.66
51	94.15	14.54	0.15	0.02	0.67	93.2	14.5	0.2	0.0	0.7	90.4	14.3	0.15	0.017	0.67
52	94.97	14.67	0.16	0.02	0.67	94.0	14.6	0.2	0.0	0.7	91.2	14.5	0.15	0.018	0.67
53	95.78	14.80	0.16	0.02	0.68	94.8	14.8	0.2	0.0	0.7	92.0	14.6	0.15	0.018	0.68
54	96.58	14.93	0.16	0.02	0.69	95.6	14.9	0.2	0.0	0.7	93.2	17.4	0.15	0.013	0.69
55	97.35	15.06	0.16	0.02	0.70	96.4	15.0	0.2	0.0	0.7	94.0	17.5	0.15	0.013	0.70
56	98.12	15.19	0.16	0.02	0.71	97.1	15.1	0.2	0.0	0.7	94.7	17.6	0.16	0.013	0.71
57	98.87	15.31	0.16	0.02	0.72	97.9	15.3	0.2	0.0	0.7	95.4	17.7	0.16	0.013	0.72
58	99.61	15.43	0.16	0.02	0.73	98.6	15.4	0.2	0.0	0.7	96.2	17.8	0.16	0.013	0.72
59	100.33	15.55	0.17	0.02	0.73	99.3	15.5	0.2	0.0	0.7	96.8	17.8	0.16	0.013	0.73
60	101.04	15.66	0.17	0.02	0.74	100.0	15.6	0.2	0.0	0.7	97.5	17.9	0.16	0.013	0.74
61	101.73	15.78	0.17	0.02	0.75	100.7	15.7	0.2	0.0	0.7	98.2	18.0	0.16	0.014	0.75
62	102.42	15.89	0.17	0.02	0.76	101.4	15.8	0.2	0.0	0.8	99.0	19.0	0.16	0.010	0.75
63	103.08	16.00	0.17	0.02	0.76	102.1	15.9	0.2	0.0	0.8	99.6	19.6	0.17	0.010	0.76
64	103.74	16.11	0.17	0.02	0.77	102.7	16.1	0.2	0.0	0.8	100.3	19.7	0.17	0.009	0.76
65	104.38	16.22	0.18	0.02	0.78	103.3	16.2	0.2	0.0	0.8	100.9	20.0	0.17	0.009	0.77
66	105.01	16.32	0.18	0.02	0.79	104.0	16.3	0.2	0.0	0.8	101.5	20.2	0.17	0.008	0.78
67	105.62	16.42	0.18	0.02	0.79	104.6	16.4	0.2	0.0	0.8	102.0	20.6	0.17	0.007	0.78
68	106.22	16.52	0.18	0.02	0.80	105.2	16.5	0.2	0.0	0.8	102.6	21.4	0.17	0.008	0.79
69	106.81	16.62	0.18	0.02	0.81	105.7	16.6	0.2	0.0	0.8	103.1	22.1	0.17	0.007	0.80
70	107.38	16.72	0.18	0.02	0.82	106.3	16.7	0.2	0.0	0.8	103.7	22.8	0.18	0.006	0.80
71	107.95	16.81	0.18	0.02	0.82	106.9	16.8	0.2	0.0	0.8	104.2	23.6	0.18	0.005	0.81
72	108.50	16.90	0.18	0.02	0.83	107.4	16.8	0.2	0.0	0.8	104.6	24.3	0.18	0.004	0.81
73	109.03	16.99	0.19	0.02	0.84	107.9	16.9	0.2	0.0	0.8	105.1	24.8	0.18	0.003	0.82
74	109.56	17.08	0.19	0.02	0.84	108.5	17.0	0.2	0.0	0.8	105.5	25.6	0.18	0.002	0.82
75	110.08	17.17	0.19	0.02	0.85	109.0	17.1	0.2	0.0	0.8	105.9	26.1	0.18	0.002	0.82
76	110.58	17.25	0.19	0.03	0.86	109.5	17.2	0.2	0.0	0.9	106.3	26.7	0.18	0.001	0.83

Table A-38. (*continue*)

	4,000 pigs					10,000 pigs					16,000 pigs				
	Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d			Intake, g/d		Excretion, lb/d		
D[a]	N	P	N	P	DM	N	P	N	P	DM	N	P	N	P	DM
77	111.07	17.33	0.19	0.03	0.86	110.0	17.3	0.2	0.0	0.9	106.8	26.7	0.19	0.000	0.83
78	111.55	17.42	0.19	0.03	0.87	110.4	17.4	0.2	0.0	0.9	107.2	27.5	0.18	0.000	0.84
79	112.01	17.50	0.19	0.03	0.87	110.9	17.4	0.2	0.0	0.9	107.6	27.7	0.19	0.000	0.84
80	112.47	17.57	0.19	0.03	0.88	111.4	17.5	0.2	0.0	0.9	108.0	27.9	0.19	0.000	0.85
81	112.92	17.65	0.19	0.03	0.89	111.8	17.6	0.2	0.0	0.9	108.4	28.1	0.19	0.000	0.85
82	113.36	17.72	0.19	0.03	0.89	112.3	17.7	0.2	0.0	0.9	108.9	28.3	0.19	0.000	0.86
83	113.78	17.80	0.20	0.03	0.90	112.7	17.7	0.2	0.0	0.9	109.3	28.5	0.19	0.000	0.87
84	114.20	17.87	0.20	0.03	0.90	113.1	17.8	0.2	0.0	0.9	109.6	28.7	0.19	0.000	0.87
85	114.60	17.94	0.20	0.03	0.91	113.5	17.9	0.2	0.0	0.9	110.0	28.9	0.19	0.000	0.88
86	115.12	18.01	0.20	0.03	0.91	113.9	17.9	0.2	0.0	0.9	110.4	29.0	0.19	0.000	0.88
87	115.38	18.07	0.20	0.03	0.92	114.3	18.0	0.2	0.0	0.9	110.8	29.2	0.19	0.000	0.89
88	115.75	18.13	0.20	0.03	0.92	114.6	18.1	0.2	0.0	0.9	111.1	29.4	0.19	0.000	0.89
89	116.14	18.20	0.20	0.03	0.93	115.0	18.1	0.2	0.0	0.9	111.5	29.5	0.19	0.000	0.90
90	116.49	18.26	0.20	0.03	0.93	115.4	18.2	0.2	0.0	0.9	111.8	29.7	0.19	0.000	0.90
91	116.84	18.32	0.20	0.03	0.94	115.7	18.3	0.2	0.0	0.9	112.1	29.8	0.20	0.000	0.90
92	117.17	18.38	0.20	0.03	0.94	116.0	18.3	0.2	0.0	0.9	112.4	30.0	0.20	0.000	0.91
93	117.49	18.44	0.20	0.03	0.95	116.4	18.4	0.2	0.0	0.9	112.8	30.1	0.20	0.000	0.91
94	119.81	18.61	0.21	0.03	0.95	118.9	18.6	0.2	0.0	1.0	113.1	30.3	0.20	0.000	0.92
95											113.4	30.4	0.20	0.000	0.92
96											116.7	30.4	0.20	0.000	0.96

[a] D = growing period, in day.

Table A- 39. Daily ration composition[a] for different animal capacities under P restriction when applicable land was 834 acres.

	4,000 pigs					10,000 pigs					16,000 pigs				
D[b]	Corn	SBM	P[c]	L[d]	PE[e]	Corn	SBM	P	L	PE	Corn	SBM	P	L	PE
1	617.9	451.4	13.0	9.0	0	627.8	442.6	10.0	10.9	1000	642.3	424.2	28.0	0.0	1000
2	634.0	462.0	13.1	9.0	0	644.0	453.2	10.2	10.9	1000	664.3	432.8	13.3	9.1	0
3	650.4	472.8	13.3	9.1	0	660.5	463.8	10.3	11.0	1000	675.9	444.4	28.4	0.0	1000
4	666.9	483.6	13.4	9.1	0	675.9	475.0	13.5	9.2	0	698.2	453.1	13.6	9.3	0
5	683.6	494.5	13.6	9.2	0	693.9	485.4	10.5	11.1	1000	710.0	465.1	28.9	0.0	1000
6	700.6	505.6	13.7	9.3	0	711.0	496.3	10.6	11.2	1000	732.9	474.0	13.9	9.4	0
7	717.7	516.7	13.9	9.3	0	726.9	507.8	13.9	9.3	0	750.5	484.5	14.1	9.4	0
8	734.9	527.8	14.0	9.4	0	748.9	515.2	11.0	11.3	1000	768.4	495.1	14.2	9.5	0
9	752.6	538.9	14.2	9.4	0	766.5	526.3	11.2	11.3	1000	786.4	505.7	14.4	9.5	0
10	770.3	550.1	14.3	9.5	0	784.2	537.4	11.5	11.3	1000	798.9	518.2	30.1	0.0	1000
11	787.7	561.7	14.4	9.5	0	802.1	548.7	11.7	11.3	1000	822.9	527.1	14.7	9.6	0
12	805.6	573.2	14.6	9.6	0	820.1	559.9	12.0	11.3	1000	835.7	539.8	30.6	0.0	1000
13	823.4	584.7	14.7	9.6	0	838.2	571.2	12.3	11.2	1000	854.2	550.6	30.8	0.0	1000
14	841.7	596.1	14.9	9.7	0	856.4	582.6	12.5	11.2	1000	878.7	559.5	15.1	9.8	0
15	859.8	607.6	15.0	9.7	0	874.8	593.9	12.8	11.2	1000	897.9	570.0	15.2	9.9	0
16	878.1	619.2	15.1	9.8	0	888.5	609.4	15.2	9.8	0	910.5	583.2	31.5	0.0	1000
17	896.5	630.8	15.3	9.8	0	907.0	620.8	15.3	9.9	0	929.4	594.1	31.7	0.0	1000
18	914.9	642.3	15.4	9.9	0	925.6	632.2	15.5	9.9	0	948.5	604.9	31.9	0.0	1000
19	933.4	653.9	15.5	9.9	0	944.2	643.6	15.6	10.0	0	973.7	613.7	15.8	10.1	0
20	951.9	665.4	15.6	10.0	0	962.9	655.0	15.7	10.0	0	992.6	624.8	15.9	10.1	0
21	970.4	677.0	15.8	10.0	0	986.4	662.1	14.3	11.0	1000	1005.9	637.7	32.5	0.0	1000
22	989.0	688.5	15.9	10.0	0	1000.3	677.7	16.0	10.1	0	1024.9	648.6	32.7	0.0	1000
23	1007.6	699.9	16.0	10.1	0	1019.1	689.0	16.1	10.1	0	1044.2	659.3	32.9	0.0	1000
24	1026.2	711.4	16.1	10.1	0	1042.7	695.9	15.1	10.9	1000	1069.7	667.7	16.4	10.3	0
25	1044.8	722.7	16.2	10.2	0	1061.4	707.1	15.4	10.8	1000	1089.0	678.5	16.5	10.3	0
26	1063.4	734.0	16.3	10.2	0	1080.2	718.2	15.6	10.8	1000	1101.8	691.6	33.5	0.0	1000
27	1081.8	745.4	16.5	10.2	0	1094.1	733.7	16.5	10.3	0	1120.8	702.2	33.7	0.0	1000
28	1100.5	756.5	16.6	10.3	0	1112.8	744.7	16.6	10.3	0	1146.4	710.3	16.8	10.5	0
29	1119.0	767.6	16.7	10.3	0	1131.4	755.7	16.7	10.3	0	1159.1	723.2	34.0	0.0	1000
30	1137.2	778.7	16.8	10.3	0	1150.0	766.5	16.8	10.4	0	1178.1	733.5	34.2	0.0	1000
31	1161.3	784.1	16.9	10.4	0	1168.5	777.3	16.9	10.4	0	1203.7	741.2	17.2	10.6	0
32	1179.6	794.9	17.2	10.3	0	1192.4	782.8	17.2	10.4	0	1222.7	751.3	17.3	10.6	0
33	1197.7	805.7	17.4	10.2	0	1210.2	793.8	17.4	10.3	1000	1235.0	764.0	34.6	0.0	1000
34	1216.0	816.1	17.7	10.2	0	1229.0	803.7	17.7	10.3	0	1253.7	773.9	34.8	0.0	1000
35	1234.0	826.6	17.9	10.1	0	1247.2	814.0	17.9	10.2	0	1283.5	776.7	17.9	10.5	0
36	1251.9	837.0	18.2	10.0	0	1265.3	824.2	18.2	10.1	0	1290.8	793.6	35.0	0.0	1000
37	1269.7	847.2	18.4	9.9	0	1282.6	834.8	18.4	10.0	1000	1320.5	796.0	18.4	10.4	0
38	1287.3	857.3	18.6	9.9	0	1301.0	844.2	18.6	10.0	0	1338.8	805.5	18.6	10.3	0

Table A-39. *(continue)*

	4,000 pigs					10,000 pigs					16,000 pigs				
D[b]	Corn	SBM	P[c]	L[d]	PE[e]	Corn	SBM	P	L	PE	Corn	SBM	P	L	PE
39	1304.8	867.3	18.9	9.8	0	1318.7	854.1	18.9	9.9	0	1357.0	814.9	18.9	10.2	0
40	1322.2	877.1	19.1	9.7	0	1335.7	864.3	19.1	9.8	1000	1375.0	824.1	19.1	10.1	0
41	1339.5	886.9	19.4	9.6	0	1353.7	873.3	19.4	9.7	0	1392.9	833.3	19.3	10.0	0
42	1356.6	896.5	19.6	9.5	0	1370.9	882.7	19.6	9.6	0	1410.6	842.2	19.6	10.0	0
43	1373.5	905.9	19.8	9.4	0	1388.0	892.0	19.8	9.5	0	1428.2	851.1	19.8	9.9	0
44	1390.3	915.2	20.0	9.3	0	1404.9	901.2	20.0	9.5	0	1445.6	859.8	20.0	9.8	0
45	1406.9	924.4	20.3	9.2	0	1421.7	910.2	20.3	9.4	0	1462.8	868.4	20.2	9.7	0
46	1423.2	933.5	20.5	9.2	0	1438.3	919.1	20.5	9.3	0	1479.8	876.9	20.5	9.6	0
47	1439.6	942.3	20.7	9.1	0	1454.7	927.8	20.7	9.2	0	1485.2	893.0	36.1	0.0	1000
48	1455.6	951.0	20.9	9.0	0	1470.9	936.4	20.9	9.1	0	1513.3	893.4	20.9	9.4	0
49	1471.5	959.6	21.1	8.9	0	1486.9	944.8	21.1	9.0	0	1529.8	901.4	21.1	9.3	0
50	1487.2	968.0	21.3	8.8	0	1502.8	953.1	21.3	8.9	0	1546.0	909.3	21.3	9.2	0
51	1502.7	976.3	21.6	8.7	0	1518.4	961.2	21.6	8.8	0	1562.1	917.1	21.5	9.2	0
52	1518.0	984.4	21.8	8.6	0	1533.9	969.2	21.8	8.7	0	1578.0	924.7	21.7	9.1	0
53	1533.1	992.4	22.0	8.5	0	1549.1	977.1	22.0	8.6	0	1593.7	932.1	21.9	9.0	0
54	1548.1	1000.2	22.2	8.4	0	1564.2	984.8	22.2	8.5	0	1597.6	947.5	36.5	0.0	1000
55	1562.8	1007.9	22.3	8.3	0	1579.0	992.3	22.3	8.4	0	1612.8	954.7	36.5	0.0	1000
56	1577.3	1015.4	22.5	8.2	0	1593.7	999.7	22.5	8.3	0	1627.9	961.8	36.5	0.0	1000
57	1591.6	1022.8	22.7	8.1	0	1607.5	1007.6	22.7	8.2	1000	1642.7	968.7	36.6	0.0	1000
58	1605.7	1030.1	22.9	8.0	0	1622.3	1014.1	22.9	8.1	0	1657.2	975.5	36.6	0.0	1000
59	1619.6	1037.1	23.1	7.9	0	1636.3	1021.0	23.1	8.0	0	1671.7	982.1	36.6	0.0	1000
60	1633.3	1044.1	23.3	7.8	0	1650.1	1027.9	23.3	7.9	0	1685.8	988.6	36.6	0.0	1000
61	1646.7	1050.9	23.4	7.7	0	1663.7	1034.5	23.4	7.8	0	1699.8	995.0	36.6	0.0	1000
62	1660.0	1057.5	23.6	7.6	0	1677.1	1041.1	23.6	7.7	0	1686.7	1007.9	68.7	0.0	1000
63	1673.1	1064.0	23.8	7.5	0	1690.3	1047.5	23.8	7.6	0	1693.3	1015.0	77.1	0.0	1000
64	1685.9	1070.4	24.0	7.4	0	1703.3	1053.7	24.0	7.5	0	1701.5	1021.9	82.5	0.0	1000
65	1698.5	1076.6	24.1	7.3	0	1716.0	1059.8	24.1	7.4	0	1708.6	1028.7	89.2	0.0	1000
66	1711.0	1082.7	24.3	7.2	0	1728.6	1065.8	24.3	7.3	0	1715.5	1035.3	95.6	0.0	1000
67	1723.2	1088.6	24.4	7.1	0	1740.9	1071.6	24.4	7.2	0	1721.7	1041.7	102.6	0.0	1000
68	1735.2	1094.4	24.6	7.0	0	1753.0	1077.3	24.6	7.1	0	1735.1	1046.8	101.5	0.0	1000
69	1747.1	1100.1	24.7	6.9	0	1765.0	1082.9	24.7	7.0	0	1738.9	1053.3	110.4	0.0	1000
70	1758.7	1105.7	24.9	6.8	0	1776.7	1088.3	24.9	6.9	0	1742.4	1059.5	119.2	0.0	1000
71	1770.1	1111.1	25.0	6.7	0	1788.2	1093.7	25.0	6.8	0	1745.3	1065.6	128.3	0.0	1000
72	1781.3	1116.4	25.2	6.6	0	1799.5	1098.8	25.2	6.7	0	1747.9	1071.4	137.4	0.0	1000
73	1792.4	1121.5	25.3	6.5	0	1810.6	1103.9	25.3	6.7	0	1751.0	1076.9	145.6	0.0	1000
74	1803.1	1126.5	25.5	6.4	0	1821.5	1108.8	25.5	6.6	0	1752.6	1082.2	154.9	0.0	1000
75	1813.7	1131.5	25.6	6.3	0	1832.3	1113.7	25.6	6.5	0	1755.2	1087.3	163.0	0.0	1000
76	1824.2	1136.2	25.7	6.3	0	1842.8	1118.4	25.7	6.4	0	1757.2	1092.2	171.3	0.0	1000
77	1834.4	1140.9	25.9	6.2	0	1853.1	1122.9	25.9	6.3	0	1761.8	1097.0	176.6	0.0	1000
78	1844.5	1145.4	26.0	6.1	0	1863.2	1127.4	26.0	6.2	0	1767.7	1101.2	180.7	0.0	1000

Table A-39. (*continue*)

	4,000 pigs					10,000 pigs					16,000 pigs				
D[b]	Corn	SBM	P[c]	L[d]	PE[e]	Corn	SBM	P	L	PE	Corn	SBM	P	L	PE
79	1854.4	1149.9	26.1	6.0	0	1873.2	1131.8	26.1	6.2	0	1776.8	1105.3	181.5	0.0	1000
80	1864.0	1154.2	26.2	5.9	0	1882.1	1136.8	26.2	6.1	1000	1785.6	1109.4	182.3	0.0	1000
81	1873.5	1158.5	26.3	5.9	0	1891.7	1140.9	26.3	6.0	1000	1794.3	1113.3	183.1	0.0	1000
82	1882.8	1162.6	26.5	5.8	0	1901.1	1144.9	26.5	5.9	1000	1802.9	1117.2	183.8	0.0	1000
83	1891.9	1166.6	26.6	5.7	0	1910.3	1148.9	26.6	5.9	1000	1811.3	1121.0	184.6	0.0	1000
84	1900.9	1170.4	26.7	5.7	0	1919.3	1152.7	26.7	5.8	1000	1819.6	1124.6	185.3	0.0	1000
85	1909.7	1174.2	26.8	5.6	0	1928.2	1156.4	26.8	5.8	1000	1827.7	1128.2	186.0	0.0	1000
86	1916.1	1180.0	26.9	5.5	0	1936.8	1160.1	26.9	5.7	1000	1835.6	1131.7	186.7	0.0	1000
87	1926.8	1181.5	27.0	5.5	0	1945.3	1163.6	27.0	5.7	1000	1843.4	1135.1	187.3	0.0	1000
88	1935.0	1185.0	27.1	5.5	0	1953.7	1167.1	27.1	5.6	1000	1851.1	1138.4	188.0	0.0	1000
89	1942.9	1188.6	27.2	5.4	0	1961.8	1170.4	27.2	5.6	1000	1858.6	1141.7	188.6	0.0	1000
90	1950.9	1191.9	27.3	5.4	0	1969.8	1173.7	27.3	5.5	1000	1866.0	1144.8	189.3	0.0	1000
91	1958.6	1195.2	27.4	5.3	0	1977.7	1176.9	27.4	5.5	1000	1873.2	1147.9	189.9	0.0	1000
92	1966.4	1198.2	27.5	5.3	0	1985.4	1179.9	27.5	5.4	1000	1880.4	1150.9	190.5	0.0	1000
93	1974.2	1200.9	27.6	5.3	0	1992.9	1182.9	27.6	5.4	1000	1887.3	1153.8	191.1	0.0	1000
94	1948.0	1236.1	27.7	5.0	0	1963.8	1220.9	27.7	5.1	1000	1894.2	1156.6	191.7	0.0	1000
95											1900.9	1159.4	192.2	0.0	1000
96											2005.0	1185.5	27.7	5.4	1000

[a] Each ingredient of ration composition was in grams per day.
[b] D = growing period, in day.
[c] P = dicalcium phosphate in grams per day.
[d] L= ground limestone in grams per day.
[e] PE=microbial phytase addition in PU per day.

VITA

Yi-Hung Lin

Candidate for the Degree of

DOCTOR OF PHILOSOPHY

Thesis: System Level Economic Analysis of Swine Diet Modifications

Major Field: Agricultural, Environmental and Resource Economics

Biographical

Personal Data: Born in Taipei, Taiwan, September, 1970, the son of Tran-Hsiang Lin and Gin-Hua Wu.

Education: Received Bachelor of Business Administration in Cooperative Economics: National Taipei University, Taipei, Taiwan in May 1993; received a Master of Art degree in International Economics: National Chung Cheng University, Chiayi, Taiwan in 1996; received a Master of Art degree in Economics: Duke University, Durham, NC in 2001; completed the requirements for the Doctor of Philosophy Degree with a focus on Agricultural Economics at Oklahoma State University, Stillwater, Oklahoma in December 2005.

Experience: Research Assistant: Oklahoma State University, Stillwater, Oklahoma.

Professional Memberships: American Agricultural Economics Association, American Economics Association.

Name: Yi-Hung Lin Date of Degree: December, 2005

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: System Level Economic Analysis of Swine Diet Modifications

Pages in Study: 395 Candidate for the Degree of Doctor of Philosophy

Major Field: Agricultural, Environmental and Resource Economics

Scope and Method of Study: The purpose of this study was to develop a system level optimization model based on the 1998 National Research Council (NRC) swine growth and nutrient requirement model. The optimal swine ration formulation model that directly accounted for the amount of nutrient excretion, and the required changes in waste treatment facilities was developed. Data from series of low protein and phosphorus feeding trials conducted at Oklahoma State University (Carter *et al*., 1999; 2000; 2001; 2003) were used to validate the simulation model. The MIXED procedure of SAS (SAS Inst. Inc., Cary, NC) and the Minos solver in GAMS 2.5 were used for statistical and optimization analysis, respectively.

Findings and Conclusions: This study revealed six important findings. *First*, the simulation results based on the initial NRC model suggest that profit could be increased by restricting growth and increasing the the percent of carcass lean during the later finishing stage. *Second*, the re-estimated parameters of DE intake, protein, and phosphorus retention equations with the experimental data on corn-soybean meal diet were significantly different than the NRC values derived from farm level data. The difference tended to reflect the difference between experimental and on farm growing conditions. *Third*, the digestable energy and proportion of nitrogen in essential amino acids were found to have significant effects on DE intake, protein, and P retention. Including the dietary nutrient effects in growth equation estimation improves the model predictability. *Fourth*, the nutritional contents of the rations and the manure, lagoon size, acres required for manure application, and waste handling cost were greatly reduced in the overall profit maximizing model as opposed to the stepwise profit maximization model. *Fifth*, the number of animals fed had little influence on the feed rations, growth trajectory, lean percent at slaughter, as well as N, P and DM excretion when there was adequate cropland for manure application. *Sixth*, microbial phytase supplement was used in the optimal rations, when land available for manure applicable was limited. The results from this study can provide a guide for swine feeding operators to improve feed efficiency, and minimize the waste cost particularly when land for manure application was limiting.

ADVISER'S APPROVAL: Arthur Stoecker