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PIC® NUTRITION AND FEEDING GUIDELINES

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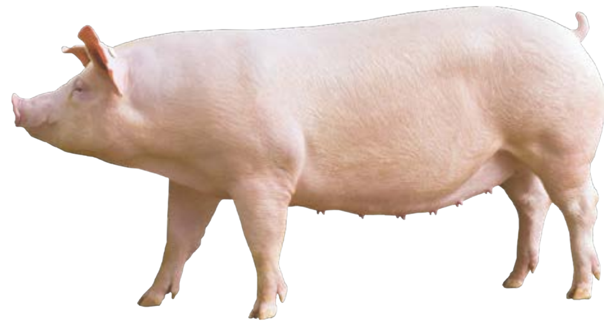
Welcome to the PIC® Nutrition and Feeding Guidelines



We are pleased to present the newest PIC® Nutrition and Feeding guidelines. Recommendations in these guidelines are based on published research, PIC® internal research, research from universities and large-scale commercial experiments.

The guidelines are composed of four parts that lay out the fundamentals of our nutrition and feeding recommendations.

1. Summarizes our logic and principles of diet formulation
2. Explains how different nutritional components can fulfill those dietary formulation principles
3. Details how basic nutrition programs vary depending on the production phase
4. Nutrient specification tables are available to optimize diets for the successful feeding of PIC® pigs

These guidelines were developed to be globally applicable, regardless of geographical location, operation size, facilities or technical equipment. The nutrient specifications have been validated in commercial environments and have been peer-reviewed by nutritionists worldwide. At all times, please follow the best practices and appropriate standards for animal health and welfare as outlined by the local governing body within your country of operation.

We hope these guidelines help you further improve the success of your operations. In case you have questions, please reach out to your PIC® account team at any time.

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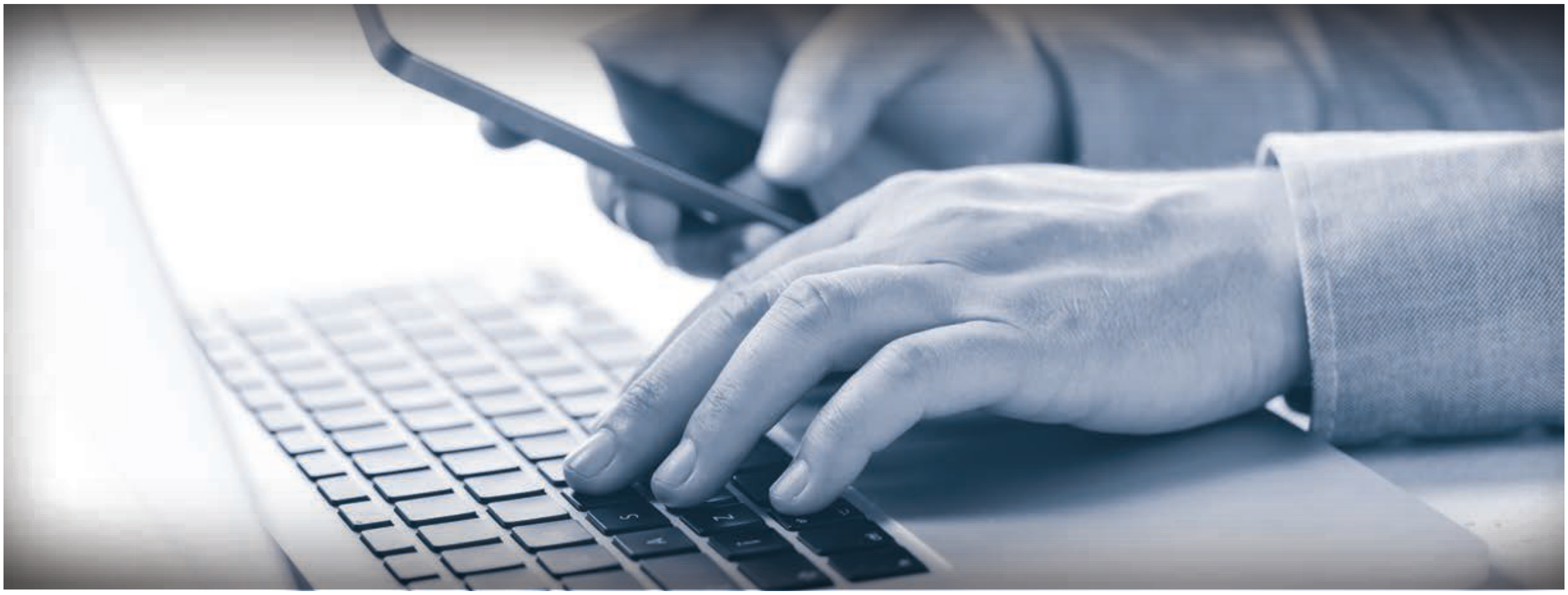
Principles and Decision Making in Diet Formulation



PIC® genetics are selected with a focus on total economics to maximize profit for the pork value chain. An adequate nutrition program is necessary to unlock the genetic potential of PIC® pigs. We recognize multiple strategies can be successfully implemented for diet formulation. Production systems worldwide typically determine a balance of maximizing animal performance, minimizing cost of production, and maximizing profitability when designing a nutrition program. Our goal at PIC® is to help our customers be the most successful pork producers in the world. Since feed is the largest production cost our goal is to provide key diet formulation principles that can be used to optimize specific nutrition programs.

- In a space short system, when pigs are profitable, average daily gain has more value.
- In times of anticipated high profitability (such as summer in the US) implement strategies to increase market weight.
- Inadequate amino acid concentration may limit the pigs’ response to energy.
- Income over feed cost is one of the most accurate ways to evaluate the feeding program.

Steps in Diet Formulation

The first step in diet formulation is to determine the pigs standardized ileal digestible (SID) lysine (Lys) to calorie ratio requirement. The second step is to define the most economical net energy (NE) concentration. The reason energy is the second step - even though it represents the largest cost - is pigs may not fully respond to the energy if SID Lys is not adequate. The third step is to define the other SID amino acid (AA) concentrations as a ratio to SID Lys. Finally, the concentrations of macro minerals, trace minerals and vitamins are defined to achieve the nutrient requirements.

The Economic Implications of Fixed Time vs. Fixed Weight

A key concept to consider when formulating diets for a specific production system is to know if the system is marketing pigs on a fixed time or a fixed weight basis:

- Fixed time, also known as space short, means the system does not have extra or flexible space in the production flow. For example, when a finishing barn reaches 120 days of placement, the pigs are marketed even if the desired market weight has not been reached, and the barn is emptied for the next group of pigs.
- Fixed weight, also known as space long, means the system has some flexible space available in the production flow. Pigs can be left in the barn until they reach the optimum weight for the carcass value payment structure.

Understanding the difference between fixed time and fixed weight is important because it changes the value of growth rate. When pigs are profitable, weight gain is more valuable in a fixed time system due to the fixed constraint on number of growing days available. However, weight gain by a given nutritional or management strategy is less valuable in a fixed weight system because pigs can stay in the barn at a fixed space cost (i.e., $0.11/pig/day) until they reach an optimum weight. This assumes the cost of space is less than a nutritional or management intervention. Production systems will often be on a fixed weight basis during winter when pigs are growing faster and on a fixed time basis during summer when pigs are growing slower. These two scenarios represent a range of economic optimums and assessing both scenarios can be an effective tool for evaluating economic sensitivity of dietary changes.

The concept of optimum nutrient concentrations to maximize profitability in a fixed time program relative to a fixed weight program is illustrated in Figure A1. Tryptophan (Trp) to Lys ratio can have a significant impact on growth rate. In this specific scenario, varying Trp to Lys ratio has a much larger economic impact on a fixed time system than a fixed weight system simply because weight gain offers a greater marginal economic return compared to the fixed weight scenario. For additional information on the value of alternative Trp to Lys ratios, please click here to download a free dynamic economic calculator for the most economic Trp to Lys ratio specific to a production system.

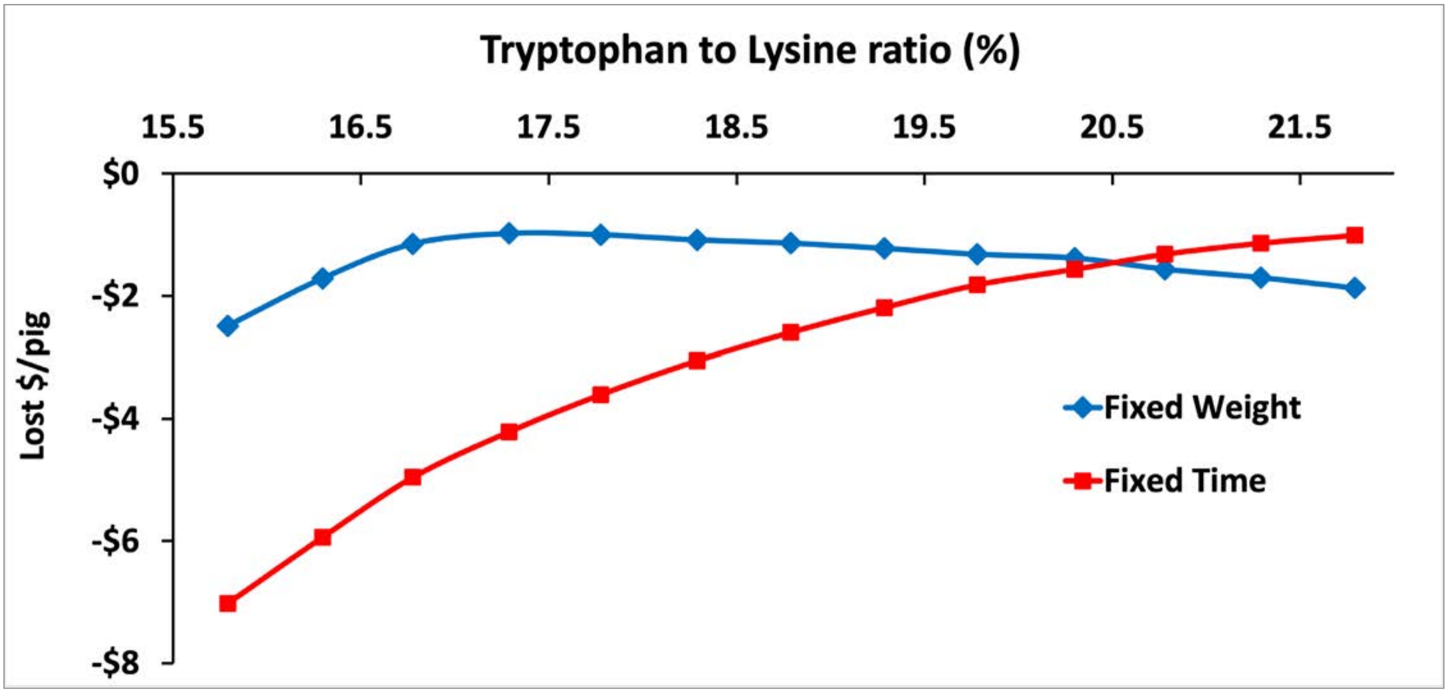


Figure A1. Standardized Ileal Digestible Trp:Lys Ratio for Economic Return on a Fixed Time and Fixed Weight Basis (PIC® 337 × PIC®1050; Kansas State University and Ajinomoto Heartland, 2016)

Strategies for Diet Formulation

Many strategies have been used for diet formulation. Production systems will typically determine a balance of:

- Maximizing animal performance
  - Average daily gain (ADG)
  - Feed efficiency (F/G)
- Minimizing cost of production
  - Feed cost per unit of gain
- Maximizing profitability
  - Income over feed cost (IOFC)
  - Income over feed and facility costs (IOFFC)
  - Income over total cost (IOTC)

A summary showing the concept of these formulation strategies is shown in Figure A2. These results show the concentrations of SID Lys to optimize the different strategies listed above. In this example, the SID Lys concentration to maximize profit is greater than that to minimize cost. The economic optimum SID Lys concentration is dynamic and depends on the ingredient and pig prices.

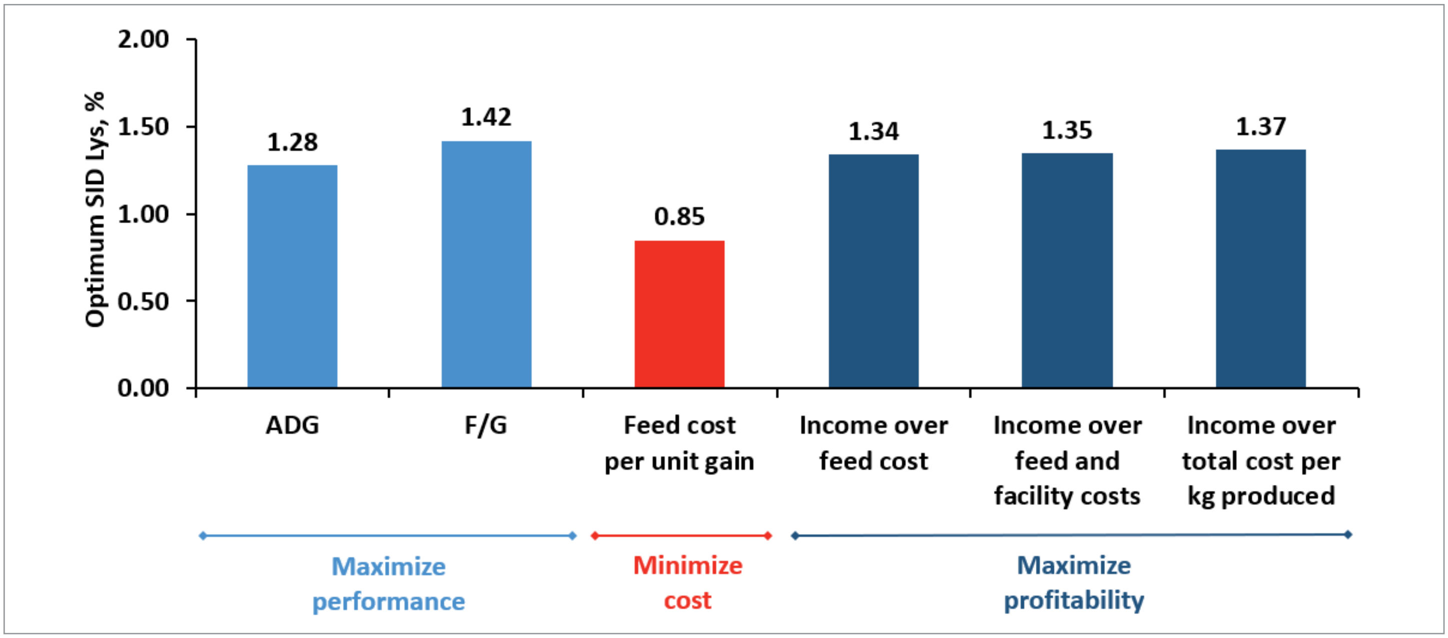


Figure A2. Example of Concentrations of Standardized Ileal Digestible (SID) Lys to Optimize Different Outcomes for PIC® Pigs (11.5 to 22.5 kg pig; PIC® internal data)

Formulating for Maximum Performance

Nutrient concentrations are selected to achieve maximum performance. Financial return is not a consideration. The optimal concentration of the nutrient could be different depending on the response criteria, an example being the SID Lys concentration required to maximize ADG is likely lower than the concentration required to optimize F/G.

Formulating for Minimum Cost

Feed cost per kg of gain is calculated by multiplying F/G by the cost per kg of feed and, therefore, feed cost per kg of gain considers F/G. The goal is to have the lowest cost per kg of gain. However, this approach does not consider any changes in ADG, carcass merit, pig price, or the cost of extra days in the barn.

Feed cost per kg gain = (F/G x $ per kg of feed)

Formulating for Maximum Profit

Diets formulated for maximum profit consider financial implications under different scenarios, balancing the nutrients needed for desired performance with dietary costs.

Income over feed cost (IOFC) considers the market price and the value of weight gain under a fixed time scenario:

IOFC = (market price per kg of live weight × weight gain) - (feed cost per kg gain × weight gain)

Income over feed and facility costs (IOFFC) adds facility cost to the IOFC equation and is more applicable in a fixed weight scenario:

IOFFC = (market price per kg live weight × weight gain) - (feed cost per kg gain × weight gain) - (cost per pig space × days in the phase)

Since feed and facility costs typically encompass the largest proportion of pig production cost and other costs are typically considered fixed costs, the IOFC is highly associated with profit. Therefore, IOFC or IOFFC is considered the best indicator of influences on profitability.

Putting it All Together

Using feed cost per kg of gain alone generally leads to the conclusion to use lower-cost diets; however, that is often not the correct decision to maximize net profit. Income over total cost considers the dilution effect of the extra gain over total costs, providing a method to appreciate the impact of extra weight sold. For example, let's assume the cost of the weaned pig is $40. A production system with 121 kg of gain from weaning to market results in a cost of $0.3306 per kg that will be related to the cost from the weaned pig. However, if a given nutritional or management strategy increases the weight gain to 123 kg, the cost per kg related to that initial weaned pig cost will decrease to $0.3252 or 1.6% reduction in cost.

To calculate income over total cost per head on a live basis ($IOTC_L$):

$IOTC_L$ = [(market price per kg live pig × market weight) - (feed cost per pig + other costs per pig + feeder pig cost)]

Or to calculate income over total cost per head on a carcass basis ($IOTC_C$):

$IOTC_C$ = [(market price per kg carcass × market weight × % yield) - (feed cost per pig + other costs per pig + feeder pig cost)]

Table A1 represent two scenarios - one with no added fat and the other with 3% added fat – and are utilized to illustrate the strategies for diet formulation.

Table A1. Scenarios and Assumptions for a Comparison Between Minimizing Cost vs. Maximizing Profit per Pig

Assumptions	Scenario 1 Fixed time/no added fat diet	Scenario 2[a] Fixed time/ 3% added fat diet
ADG, kg	0.816	0.841
Feed/Gain	2.800	2.632
Days on feed	112	112
Diet cost, $/kg[b]	0.230	0.245

[a]Assuming each 1% added fat improves gain by 1% and F/G by 2%. This response can vary from system to system and by season.
[b]Assuming costs of soybean meal, corn, and choice white grease at $386/tonne, $0.14/kg, and $0.68/kg, respectively.

Diet cost should include manufacturing and delivery, not just ingredient cost. This is a more accurate reflection of the total cost of the feed consumed and the value of the performance differences.

Scenario 1 (Sc1; no added fat)
Weight gain = 112 days × 0.816 kg ADG = **91.4 kg gain in the finishing**
Feed cost per kg gain = 2.80 F/G × $0.230 feed cost/kg = **$0.644**
Feed cost per pig = 91.4 kg gain × $0.644 feed cost/kg gain = **$58.86**

Scenario 2 (Sc2; 3% added fat)
Weight gain = 112 days x 0.841 kg ADG = **94.2 kg gain in the finishing**
Feed cost per kg gain = 2.632 F/G × $0.245 feed cost/kg = **$0.645**
Feed cost per pig = 94.2 kg gain × $0.645 feed cost/kg = **$60.76**

Scenario 1 has slightly lower feed cost per kg of gain and it has the lowest feed cost per pig. However, in scenario 2 there are more kilograms produced per pig and this needs to be taken into consideration.

Income Over Feed Cost

Assumption:

- Live pig price = $1.21/kg

IOFC (Sc1) = ($1.21 pig price/kg x 91.4 kg gain) – ($58.86 feed cost per pig) = **$51.73 per pig**
IOFC (Sc2) = ($1.21 pig price/kg x 94.2 kg gain) – ($60.76 feed cost per pig) = **$53.22 per pig**

The income over feed cost per pig in scenario 2 is $1.49 higher than scenario 1, thus, adding fat in this scenario is more profitable.

Income Over Total Cost

Assumptions:

- Carcass yield = 74%
- Carcass price = $1.65/kg
- Feeder pig cost (23 kg) = $55
- Weight gain = 91.4 kg
- Other costs (facilities/transport/medicines/vaccines/slaughter) = $14.56 per pig

<u>Calculations on a live basis:</u>

IOTCL (Sc1) = [$1.21 x (23+91.4)] - ($58.86+$14.56+$55.0) = **$10.00 per pig**
IOTCL (Sc2) = [$1.21 x (23+94.2)] - ($60.76+$14.56+$55.0) = **$11.49 per pig**

Scenario 2 (3% added fat) is $1.49 per pig more profitable than scenario 1 (no added fat) in this market situation on a live basis.

<u>Calculations on a carcass basis:</u>

IOTCC (Sc1) = [$1.65 x (23+91.4) x 0.74] - ($58.86+$14.56+$55.0) = **$11.26 per pig**
IOTCC (Sc2) = [$1.65 x (23+94.2) x 0.74] - ($60.76+$14.56+$55.0) = **$12.78 per pig**

Thus, scenario 2 (3% added fat) is $1.52 per pig more profitable than scenario 1 (no added fat) in this market situation on a carcass basis.

Although cost was increased in scenario 2 with the inclusion of 3% fat in the diet, the increase in income resulted in an increased IOFC and IOTC compared to scenario 1 with no added fat (Table A2).

Table A2. Absolute and Relative Economic Differences Between Scenarios 1 and 2

Assumptions	Differences (Scenario 2 – Scenario 1)	
	Absolute	Relative (%)
Diet cost, $/kg	0.015	+6.5
Feed cost per pig, $/pig	1.90	+3.2
Feed cost per kg produced, $/kg	0.002	+0.3
IOFC, $/pig	1.49	+2.9
IOTC, $/pig (Live weight basis)	1.49	+14.9
IOTC, $/pig (Carcass basis)	1.52	+13.5

Overall, there are multiple strategies and approaches for diet formulation. It is important to use an approach that considers the value of performance (i.e., ADG, F/G, yield) and the fixed time or fixed weight system. Keep in mind that the system may be fixed time in some months and fixed weight in others. Therefore, using approaches such as income over feed (and facility) costs or income over total cost on a carcass basis are suitable solutions to maximize the profitability of swine operations.

Seasonal Diet Formulation

Historically, as pork supply in the US decreases in summer months, market hog prices increase (Figure A3). The reduction is likely linked to lower farrowing rates from seasonal infertility in summer matings, reduced growth due to lower feed intake during warmer months, and stronger market demands in summer. The months with the highest price may vary across the globe as different regions are affected by climate changes and market demands. There will likely still be some price by season variation.

Using the US as an example, in order to make the most out of the increased pig price during summer, the nutritionist and production team need to focus proactively on strategies to increase market weight in the desired months. The application of those strategies depends on the current nutrient concentrations being used in the production system. Common strategies include, but are not limited to:

- Increased energy concentrations
- Increased amino acid concentrations
- Increased copper concentrations
- Use of ractopamine and/or other growth-promoting additives, if allowed

PIC® developed an Excel-based calendar tool to help nutritionists and producers identify dates to update each diet to get the most out of the high pig price during the desired months, click here to access the tool.

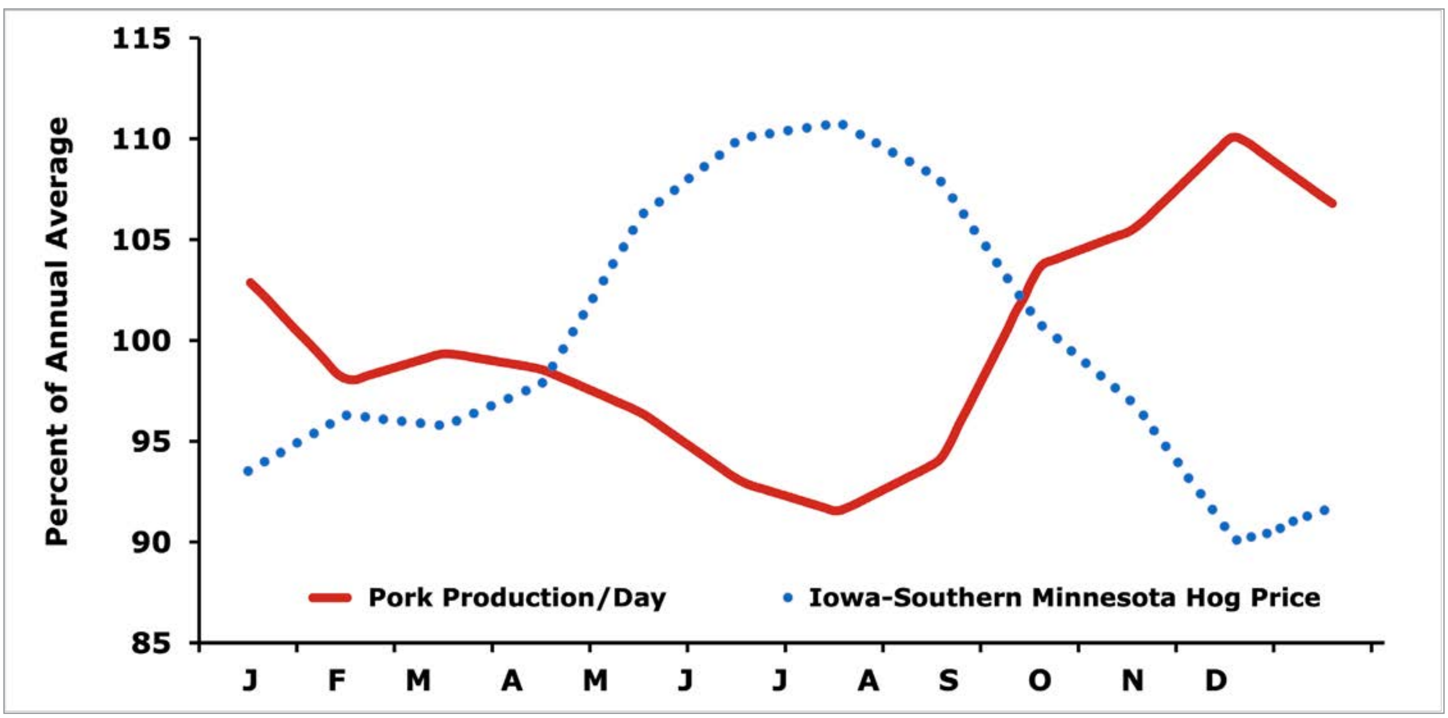


Figure A3. US Seasonal Pork Supply and Price Indexes from 1980 to 2016 (adapted from EMI Analytics)

Energy

Dietary energy represents the biggest cost of any diet. Understanding dietary energy throughout the different production phases on performance and economic implications is important.

- There are different ways to describe dietary and ingredient energy values.
- Metabolizable and net energy systems being the most common.
- Accurate ingredient energy values estimates are needed to evaluate their relative value in a diet properly.
- Pigs will increase feed intake to meet their energy needs assuming:
  - The diet is not so low in energy or so high in fiber that they cannot fully compensate.
  - Adequate feeding management, health status, and environmental conditions to allow for unrestricted nutrient access.
- PIC® and Kansas State University developed a model to help determine the dietary energy concentration that delivers the most income over feed cost. Pig price and the ingredient cost are major model drivers.

Digestible energy (DE) is gross energy (GE) intake minus the heat of combustion of fecal material (Figure B1). Metabolizable energy (ME) is DE minus the heat of combustion of urine and gas production. Gas production in pigs is generally ignored. Net energy (NE) is ME minus the heat increment, which is the heat of digestion and nutrient metabolism. Net energy can be further divided into NE for maintenance (NE_m) and NE for production (NE_p). Net energy for maintenance is the energy needed to sustain life and maintain homeostasis (i.e., body temperature). Net energy for production is the energy used in synthesis of protein, fat, fetal development, and milk production. Thus, NE should be the most accurate system to predict growth performance (Nitikanchana et al., 2015).

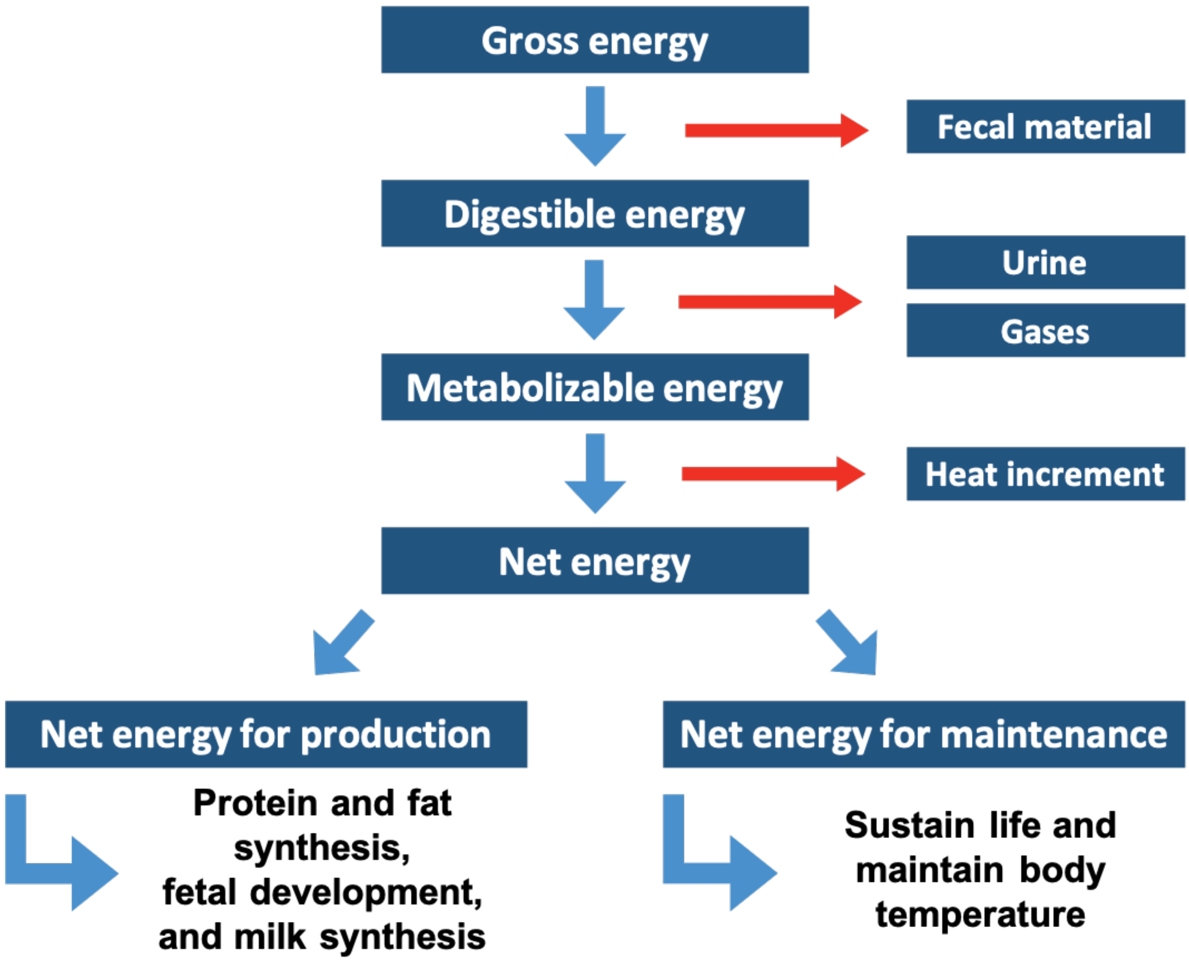


Figure B1. Utilization of Dietary Energy by Pigs

Ingredients with high-fiber (i.e., distiller's dried grains with solubles, wheat middlings) or high-protein (i.e., soybean meal) generate greater heat increment during digestion (Figure B2). With high-fiber or high-protein, there is a greater difference between ME and NE than ingredients with moderate fiber and protein concentrations. It is important to take into consideration that heat increment can be used by the pigs as a source of heat when they are below their thermoneutral zone. Thus, high-fiber and high-protein diets are not as detrimental during the winter season when feed intake is not limited by hot weather or the extra heat production can be used by the pig to maintain body temperature.

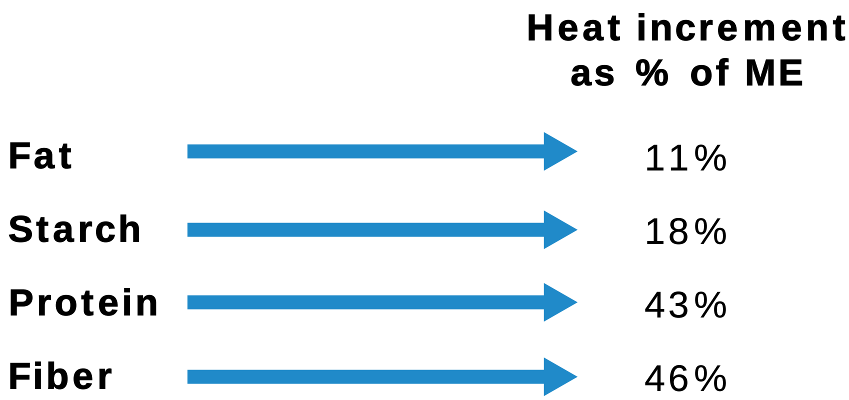


Figure B2. Heat Increment as a Percentage of Metabolizable Energy (ME) for Pigs. Adapted from Noblet & Van Milgen (2004) and Rijnen et al. (2003)

Ingredient Energy Value Importance

Nutrient loading values of ingredients used in formulation are important. It is critical to be consistent in the ingredient database used. For example, using two different ingredient databases, such as National Research Council (NRC, 2012) and Central Bureau for Livestock Feeding (CVB, 2008), can result in different concentrations of ME (3.3% difference), NE (4.2% difference), and SID Lys (2.2% difference) for the same diet (Table B1). This comparison shows the importance of using a consistent reference for energy values.

For ingredients not available in ingredient databases, energy values can be calculated using a variety of methods. These methods include a comparison to ingredients with similar composition, titration studies, or calculations based on the proximate analysis. Consider adjusting the energy of in-house ingredients based on their difference from reference ingredients' moisture. All energy values used in PIC®'s recommendations and tools use NRC (2012). Comparing your diet energy to the same diet using NRC 2012 values can give you an idea of an energy adjustment you can use when using the PIC® tools. When using PIC® Tools, we would not suggest giving energy or amino acid release values by enzymes.

Table B1. The Same Diets Formulated with Two Different Ingredient Databases (NRC 2012 vs. CVB 2008)

Item	Percentage, %
Corn, yellow	70.99
Soybean meal, solv. extr., Crude Fiber < 4%, Crude Protein < 48%	25.19
Corn oil	1.00
Calcium carbonate	0.95
Monocalcium phosphate	0.78
Salt (NaCl)	0.37
L-Lys HCl	0.17
DL-Methionine	0.04
L-Threonine	0.02
Vitamin and trace mineral premix	0.50
Total, %	**100**

	NRC, 2012	CVB, 2008
Metabolizable energy, kcal/kg	3,342	3,232
Net energy, kcal/kg	2,515	2,414
Standardized Ileal Digestible Lys, %	0.93	0.91

A corn-soybean meal-based diet and a high-fiber ingredient-based diet were formulated to have the same ME concentration (Table B2). Note the diets have the same ME but the high fiber ingredient diet has 2.5% less NE. This suggests if the NE concentration is more accurate, feed efficiency would be 2.5% poorer. Therefore, scenarios where high fiber ingredients are priced into the diet, the NE differences affect the economic calculations but the comparison on an ME basis do not.

Table B2. Diets with Same Metabolizable Energy (ME) but Different Net Energy (NE) Using NRC (2012) Ingredient Values

Item	Corn and soybean meal diet	High fiber ingredient diet
Corn, yellow	70.99	37.48
Corn DDGS, < 4% Oil	---	30.00
Wheat middlings	---	19.00
Soybean Meal, solv. extr., Crude Fiber < 4%, Crude Protein < 48%	25.19	7.11
Corn oil	1.00	3.52
Calcium carbonate	0.95	1.28
Monocalcium phosphate	0.78	---
Salt (NaCl)	0.37	0.39
L-Lys HCl	0.17	0.57
L-Threonine	0.02	0.10
L-Tryptophan	---	0.04
DL-Methionine	0.04	0.03
Vitamin and trace mineral premix	0.50	0.50
Total, %	**100**	**100**
Metabolizable energy, kcal/kg	3,342	3,342
Net energy, kcal/kg	2,515	2,452
Standardized Ileal Digestible Lys, %	0.93	0.93

Grow-Finish Diet Energy Response

Understanding how pigs respond to changing dietary energy concentration is essential to achieve the most profitable dietary energy concentration. The impact of dietary energy concentration on performance of PIC®337 sired pigs was determined (Table B3). Diets were balanced on a SID Lys:Mcal ME basis according to PIC® recommendations (Appendix A). Minimum SID AA ratios were maintained in all diets.

Table B3. Effects of Energy Concentration on Growth Performance of Grow-Finish Pigs[a]

Item	Dietary energy concentration	
	Low	High
Initial weight, kg	21.8	21.8
Final weight, kg	130.8	130.7
Days on feed	123	119
Average daily gain, kg	0.894	0.921
Average daily feed intake, kg	2.40	2.26
Feed to gain ratio	2.69	2.45
Metabolizable energy (ME) intake, Mcal/day[b]	7.98	7.98
Net energy (NE) intake, Mcal/day[b]	5.86	6.08
Caloric efficiency, Mcal of ME/kg	8.82	8.54
Caloric efficiency, Mcal of NE/kg	6.50	6.51

[a]Adapted from PIC® Executive Summary 51.

[b]Dietary energy concentrations were calculated assuming nutrient values from the NRC (2012) database.

Feeding a series of high-energy diets numerically resulted in a 3.1% improvement in average daily gain (ADG), a 6.1% reduction in average daily feed intake (ADFI), and an improvement of 8.7% in feed efficiency. Daily ME intake was similar between pigs fed different energy concentrations, whereas pigs fed low NE diets consumed approximately 3.5% less energy than pigs fed high NE diets. This resulted in a 3.1% poorer caloric efficiency for pigs fed low energy diets on an ME basis, and a similar caloric efficiency on a NE basis. Although FCR was different, pigs on the lower NE diets were not necessarily less efficient in energy utilization, and the NE system appears to be more accurate compared to the ME system.

A more recent commercial trial measured the effects of a wide range of dietary NE concentration and dietary neutral detergent fiber (NDF) on performance of 30 to 130 kg grow-finish pigs (Lu et al., 2020). A total of 2,058 PIC® pigs (PIC®380 x Camborough®) were assigned to 1 of 7 dietary treatments, which contained increasing NE concentrations (2.11 to 2.73 Mcal/kg) in conjunction with decreasing dietary NDF concentrations (24.2 to 9.5%). More fibrous ingredients/less oil were used in the lower energy diets, while more corn and oil were used in the higher energy diets. The 2.42 Mcal/kg treatment was considered equivalent in energy to a corn-soybean meal-based diet.

Increasing dietary NE and reducing dietary fiber increased ADG, decreased ADFI, improved carcass F/G, and increased daily NE intake (quadratic, $P < 0.05$; Figure B3). The lowest energy treatment had 14% less energy compared to the equivalent of a corn-SBM diet. Pigs were only able to consume 9% more feed of the lowest energy treatment, which resulted in a 7% reduction in ADG. This trial's results were not in agreement with Schinckel et al. (2012), who reported that pigs could compensate for the decreased energy content of the diets by eating more. The difference between studies could be due to the greater magnitude of NDF increment in the current trial (NDF increased by 11.3 vs. 4.4%).

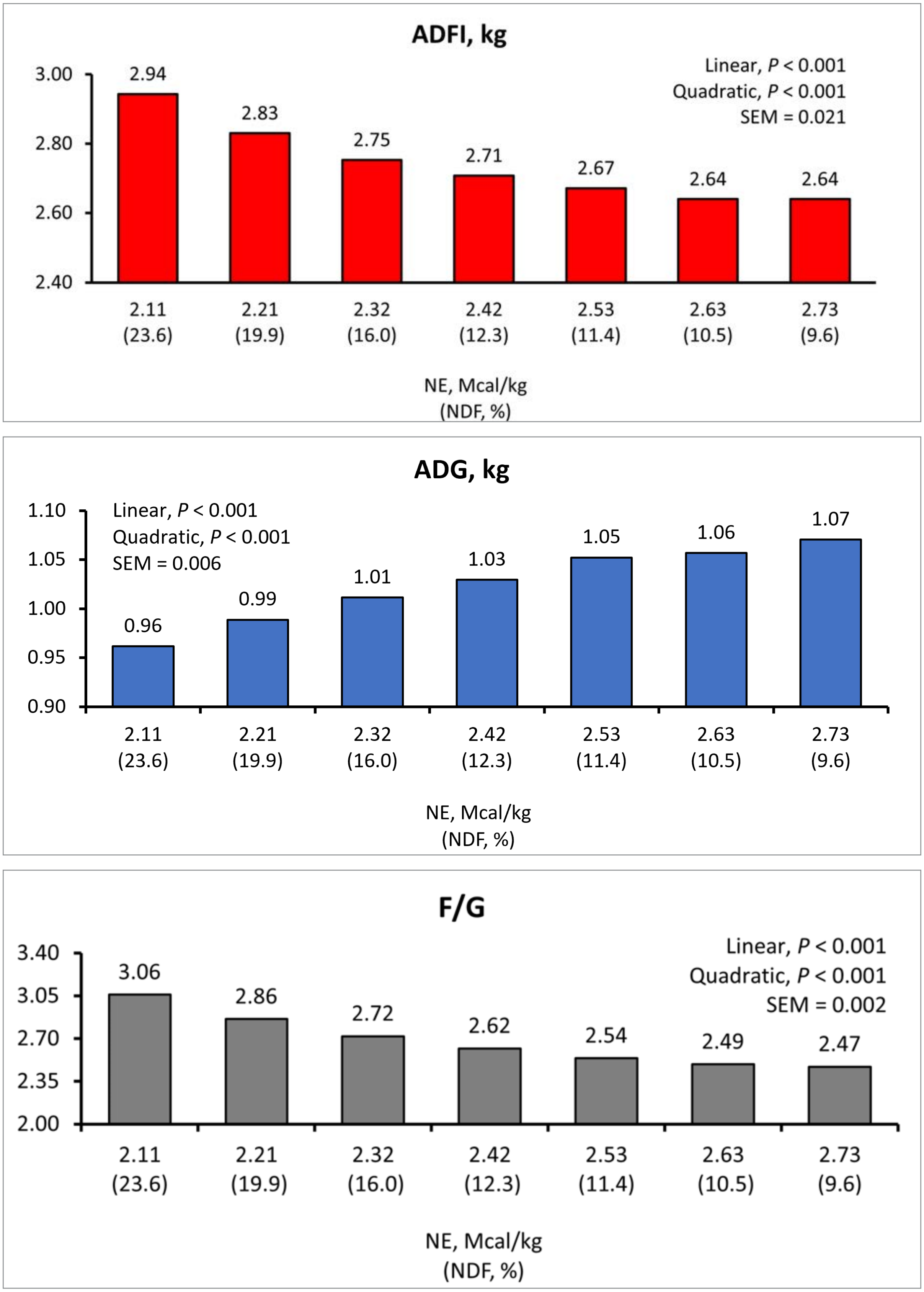


Figure B3. Effects of Energy and Fiber Concentrations on Average Daily Feed Intake (ADFI), Average Daily Gain (ADG), and Feed to Gain (F/G) of Grow-Finish Pigs

Removal rates and removal due to vices were numerically greater for pigs fed the lowest NE and highest NDF diets (Figure B4). We hypothesize the greater vice prevalence was associated with inadequate nutrient access. It appears that the pig increases ADFI when fed low energy diets to a point where gut capacity becomes limiting and nutrient intake per day is reduced. We also speculated that higher fiber, lower energy, and lower bulk density diets take longer for the pig to consume an equal amount of calories. Thus, when feeding lower energy and higher NDF diets, feeder space and pan coverage may become more critical. Production personnel should be aware of diet changes so they can adjust feeder/pen space and feeder adjustments to help pigs reach these higher intake levels. This study indicates that restricting feed intake reduces pig performance. Laskoski (2019) reported increased ear and tail lesions with increasing number of pigs per feeder hole. More information on feeder space and adjustment recommendations can be found in the PIC® Wean to Finish Manual, click here.

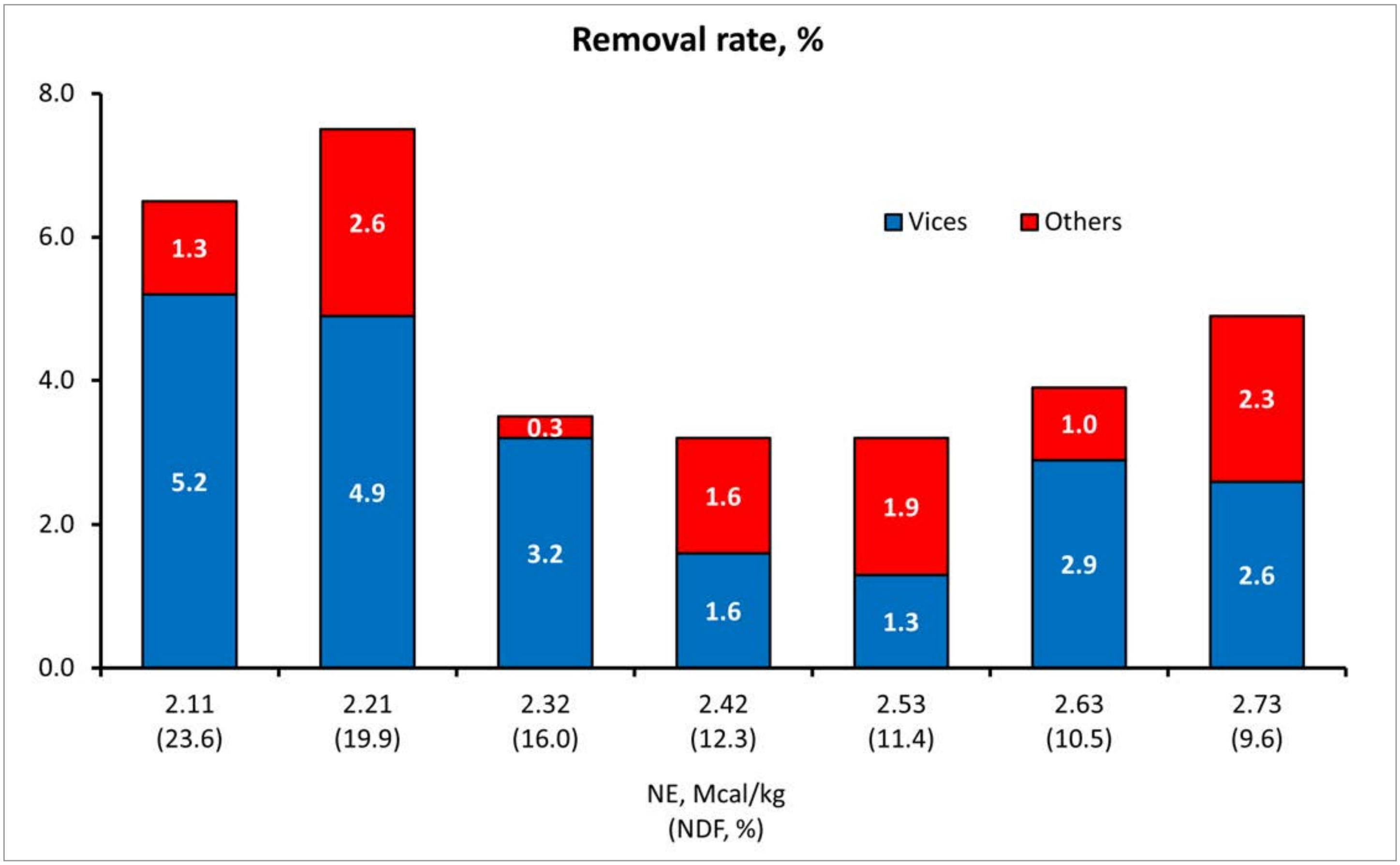


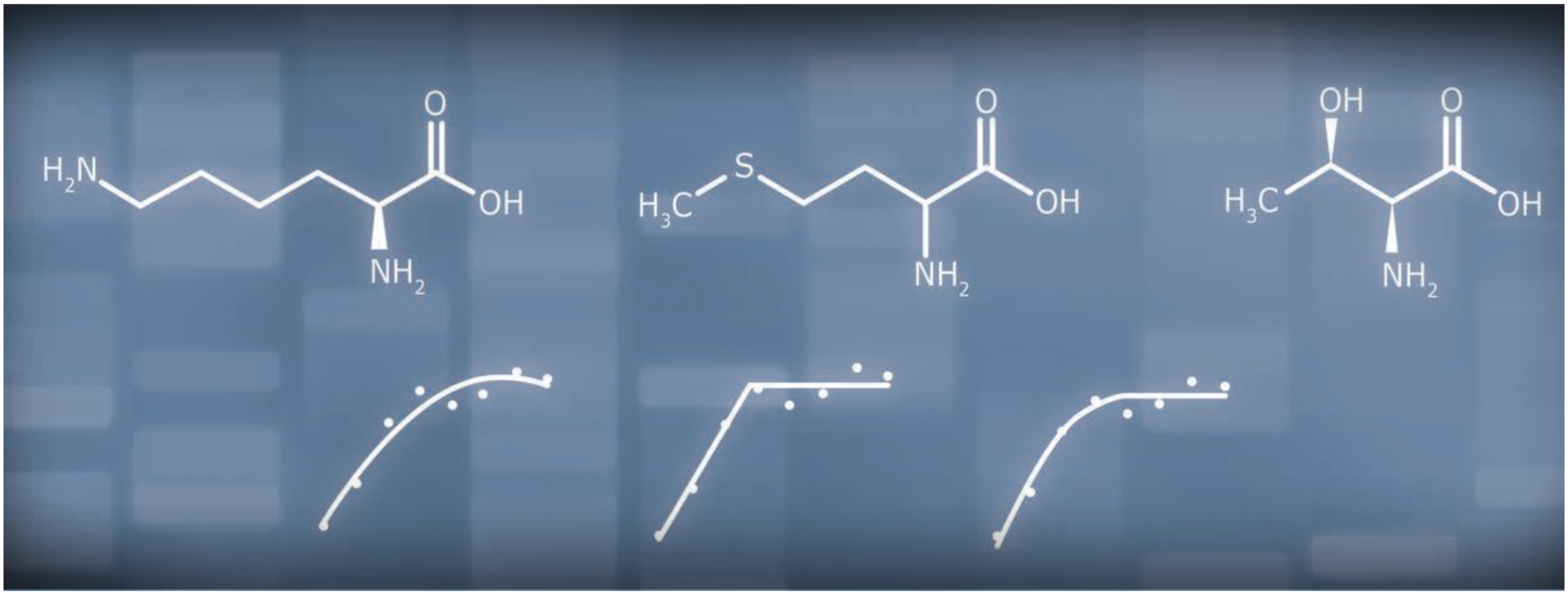
Figure B4. Effects of Energy and Fiber Concentrations on Removal Rate and Prevalence of Abnormal Behaviors

Economic Model for Optimum Energy Concentration

Regression equations have been developed and validated to predict the growth rate and feed efficiency of grow-finish pigs (Nitikanchana et al., 2015) and impact on carcass yield (Soto et al., 2019a) dependent on dietary NE fed. These equations were used to model the optimum dietary NE content that yields the highest income over total cost per pig on a live or carcass basis. PIC® and Kansas State University collaboratively developed a tool based on this model and farm-specific inputs to yield the dietary energy concentration the highest economic benefit taking into consideration changing production and economic scenarios. Click here to access this tool and instructions.

Section C

Proteins and Amino Acids



Proteins are made up of amino acids. Amino acids are essential for efficient growth and reproduction. Pigs have specific amino acid requirements during different phases of life.

- There are different ways to describe amino acids in swine diets.
- We believe standardized ileal digestible amino acids are the most practical.
- The ideal protein concept is where other essential amino acids are typically supplied as minimum ratios to dietary SID Lys content.
- The minimum ratios change with the different stages of production.
- Pigs require ~20 g of SID Lys to deposit 1 kg of body weight gain.
- As pigs become more feed efficient with genetic improvement, the amino acid concentration of the diet needs to increase.
- Several research trials suggest grow-finish pig growth performance is reduced when dietary crude protein concentrations are below 13%.
- The amino acid concentration that maximize growth performance may not be the most cost effective. The SID Lys economic calculator can help in making that decision.

Essential and Nonessential Amino Acids

There are 20 amino acids that make up proteins. Amino acids are classified as dietary essential and nonessential (Table C1). Diets are typically formulated to meet the pig's essential amino acid requirements because pigs cannot synthesize essential amino acids at the required rate. Nonessential amino acids can be synthesized by pigs provided there is enough nitrogen in the diet. Some amino acids may be classified as conditionally essential, as they may be required only under certain dietary and physiological conditions.

Table C1. Essential, Nonessential, and Conditionally Essential Amino Acids (Adapted from NRC, 2012)

Essential	Nonessential	Conditionally essential
Histidine	Alanine	Arginine
Isoleucine	Asparagine	Cysteine
Leucine	Aspartate	Glutamine
Lysine	Glutamate	Proline
Methionine	Glycine	Tyrosine
Phenylalanine	Serine	
Threonine		
Tryptophan		
Valine		

Although energy represents the major cost of any diet, a large portion of the response to energy depends on having adequate amino acids. Before determining the most economical energy value, determine the amino acid requirements. To obtain desired performance, all essential amino acids must meet the pig's needs.

Expressing Amino Acid Requirements

Amino acids can be expressed in multiple ways:

- **Total**: represents all the amino acids the ingredient contains and are found in an amino acid assay. The downside is the dramatic difference in amino acid digestibility between feedstuffs is not considered. Other methodologies have been developed to account for digestibility differences:
  - **Bioavailability**
    is estimated by a method called "slope-ratio assay" and refers to the digestible plus post-absorptive utilization of the amino acids at the tissue level. However, this method is the most expensive and the determined amino acids availabilities are likely not additive in mixtures of feed ingredients (Gabert et al., 2001).
  - **Digestibility**
    can be expressed as total tract or ileal digestibility. The total tract digestibility estimate is based on the difference between ingested and recovered amounts of amino acids from the feces. This may overestimate the digestibility because of the microbial fermentation in the large intestine. In contrast, the ileal digestibility estimate is based on the difference between the ingested and recovered amounts of amino acids from the ileal digesta, being a more accurate estimate. The ileal digestibility can be further divided:
    - **Apparent Ileal Digestibility (AID):** does not account for endogenous amino acid losses.
    - **Standardized Ileal Digestibility (SID):** accounts for basal endogenous amino acid losses.
    - **True Ileal Digestibility (TID):** accounts for basal and specific endogenous amino acid losses.

Typically, as the energy in the diet increases, daily feed intake is reduced while caloric intake is similar. Expressing amino acids relative to dietary energy content (i.e. Lys to calorie ratio), adjusts the amino acid concentrations for different energy concentrations (Chiba et al., 1991; De La Llata et al., 2001). As energy goes up, Lys goes up; as energy goes down, Lys goes down; but the Lys to calorie ratio stays the same regardless of the energy of the diet. This adjustment ensures amino acids are adjusted based on changes in feed intake and growth rate due to changes in dietary energy density.

Amino Acid Ratios

The NRC (2012) defined essential amino acid requirements for each stage of production. Subsequent research-based modifications have been made based on recent research using PIC® pigs. This manual reports the amino acid requirements on a SID basis. The Lys requirements are expressed as SID Lys to energy ratio. Requirements for other essential amino acids are normally expressed as minimums in relation to the SID Lys since Lys is most likely to be first limiting in the diet. Also, the amino acid requirements we recommend were determined using NRC (2012) ingredient nutrient concentrations, including metabolizable and net energy. The suggested minimum ratio of dietary amino acids for each phase is described in the PIC® Nutrient Specification Tables.

Grow-Finish Pig Amino Acids Requirement Recent Advances

PIC® pigs' lean gain and efficiency increases are being expressed in production systems globally. Adequate amino acid supply is important for successful pig production. Feeding diets below the amino acid requirement will decrease protein deposition and increase fat deposition (Main et al., 2008). Approximately 20 g of SID Lys is required to deposit 1 kg of body weight gain (Goodband et al., 2014; Orlando et al., 2021). With an increase in growth rate and improved feed efficiency, it is expected that the dietary Lys recommendation should be increased to match the pig's needs.

An update of the meta-analysis that generated the PIC® recommendations for SID Lys in 2016 was conducted with a total of 29 experiments performed between 2013 and 2020 under commercial conditions utilizing 48,338 pigs (Orlando et al., 2021). The two most recent trials in this meta-analysis were conducted with the progeny of the top 15% high index sireline boars from a PIC® elite farm. The models were developed for mixed-gender pigs, and used the PIC®337 growth curve to estimate the recommendations for barrows and gilts. The SID Lys to calorie ratio curves were built for both the ME and NE basis according to the feed ingredient composition in NRC (2012). The NE to ME ratio observed in the meta-analysis data ranged from approximately 0.72 to 0.74. The PIC® 2020 SID Lys recommendations are based on the average for ADG and feed efficiency (G:F), at which concentrations approximately 100% of maximum ADG and 99.4% of maximum G:F are achieved. The updated biological requirements remained similar compared to the PIC® 2016 recommendations; however, the requirement estimates have been adjusted for late nursery and late finishing phases (Figure C1).

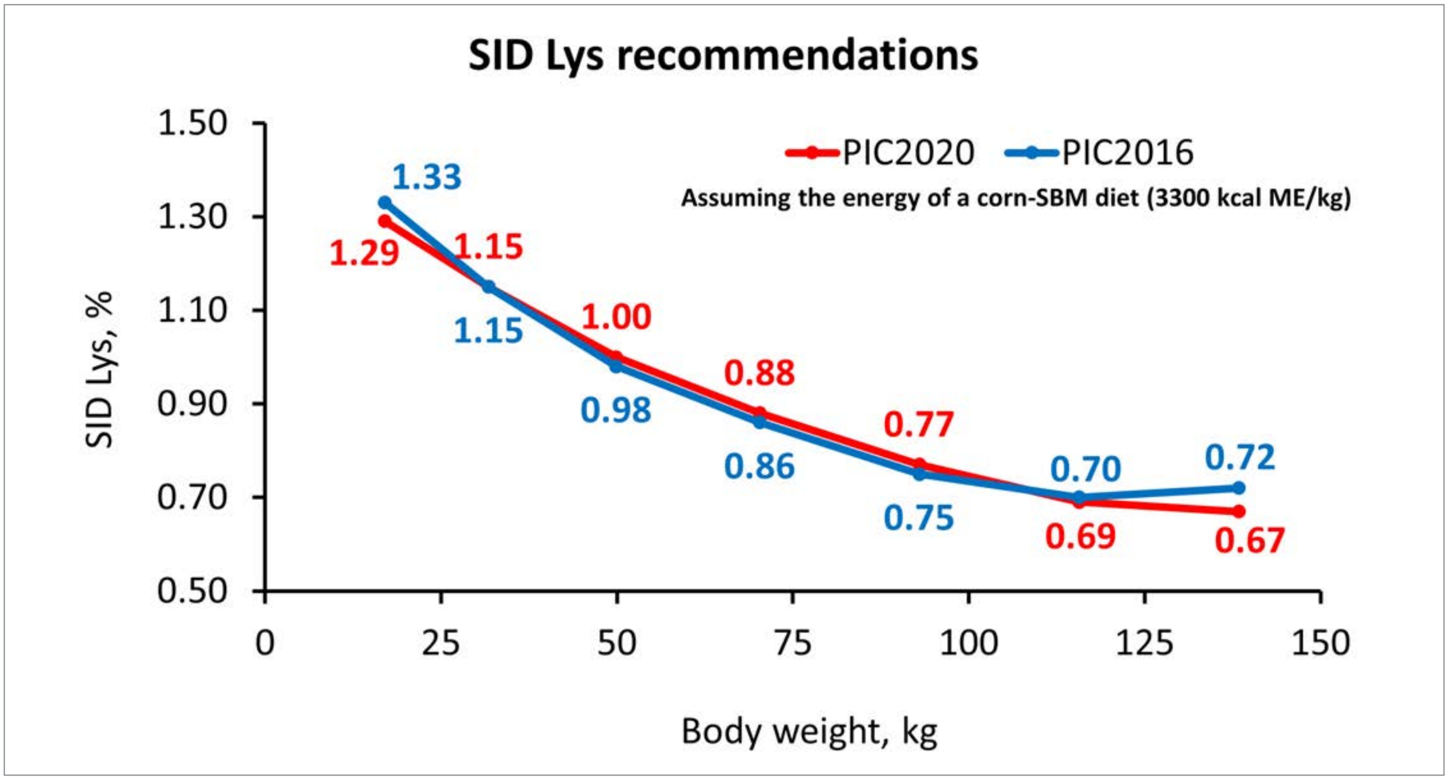


Figure C1. Dietary Percentage SID Lys Recommendations for PIC® Pigs in 2016 and 2020 Based on the Energy Equivalent to a Corn-Soybean Meal Diet

Below are the regression equations used to estimate the PIC® SID Lys to calorie ratio requirements based on gender and body weight:

SID Lys for Mixed Gender (Barrows and Gilts), g/Mcal of NE = 0.0000327185 × (weight, kg x 2.204622)^2 - 0.0214484253 × (weight, kg x 2.204622) + 6.0773690201.

SID Lys for Mixed Gender (Barrows and Gilts), g/Mcal of ME = 0.0000255654 × (weight, kg x 2.204622)^2 - 0.0157978368 × (weight, kg x 2.204622) + 4.4555073859.

SID Lys for Barrows if weight is < 40 kg = the same SID Lys:Mcal of mixed gender;
SID Lys for Barrows if weight is > 40 kg = g SID Lys:Mcal for mixed gender - (-0.0000000031 × weight, kg^4 + 0.0000013234 × weight, kg^3 - 0.0002087068 × weight, kg^2 + 0.0142221655 × weight, kg - 0.3126825057) × g SID Lys:Mcal for mixed gender

SID Lys for Gilts if weight is < 40 kg = the same SID Lys:Mcal of mixed gender;
SID Lys for Gilts if weight is > 40 kg = g SID Lys:Mcal for mixed gender + (-0.0000000031 × weight, kg^4 + 0.0000013234 × weight, kg^3 - 0.0002087068 × weight, kg^2 + 0.0142221655 × weight, kg - 0.3126825057) × g SID Lys:Mcal for mixed gender

SID Lys for Boars if SID Lys for Barrows × [0.0023 × weight, kg + 0.9644] is < SID Lys for Gilts = the same SID Lys:Mcal of Gilts.
SID Lys for Boars if SID Lys for Barrows × [0.0023 × weight, kg + 0.9644] is > SID Lys for Gilts = SID Lys for Barrows × [0.0023 × weight, kg + 0.9644]

Market weights are increasing worldwide, and with that, we need to understand the nutrient requirements of heavier pigs. A commercial study with 990 pigs (PIC® 337 x Camborough®) housed in mixed-sex pens was conducted to determine the SID Lys requirement of pigs weighing 130 to 150 kg (Orlando et al., 2018). Results indicated the breakpoint for optimum feed efficiency of late finishing pigs at 2.21 g SID Lys:Mcal ME. The Lys requirement does not have a dramatic decrease after 150 kg of bodyweight, and data from this study were included in the PIC® 2020 meta-analysis which now more accurately reflects the Lys recommendations at increased market weights.

Due to economic and environmental concerns, reduction of crude protein (CP) percentages by partially replacing the amino acids from protein sources with feed grade amino acids is widely practiced globally. Although pigs do not have a specific protein requirement, recent studies have shown that low crude protein can reduce pig performance. This is more evident in late finishing pigs fed diets below 13% crude protein, even when adequate amino acid ratios are met (Tous et al., 2014; Soto et al., 2019b). Several potential explanations have been investigated, such as deficiency of nonessential amino acids or other nutrients provided by the protein source, crude protein source, soybean meal concentration, soy isoflavone concentration, dietary electrolyte balance, choline, and potassium (Rojo, 2011; Ball et al., 2013; Rochell et al., 2015; Mansilla et al., 2017; Thomas et al., 2018). Further research is needed to understand the cause of reduced performance when pigs over 100 kg of bodyweight are fed diets below 13% crude protein but with seemingly adequate amino acid concentrations.

Biological and Economic Models for Optimum SID Lys Concentration

Genetic selection for increased growth and improved feed efficiency over the last decade prompted the need to re-evaluate nutrient recommendations to achieve the pig's genetic potential. Results from the previously mentioned meta-analysis served as a basis for the development of a tool to estimate the SID Lys biological requirement for PIC® pigs under different weight ranges.

Lys concentration has a large impact on diet cost. Depending on the economic scenario, the biological SID Lys concentration to maximize growth rate may not result in maximum profitability. PIC® has developed an Excel-based tool to help users determine the economics of current SID Lys concentrations being fed compared to the biological Lys requirement under different financial situations. Click here to access these tools and instructions.

Section D

Macrominerals

Macrominerals are involved in many processes ranging from structural framework of DNA and RNA to bone development, electrolyte balance, and growth performance. Fine-tuning the macromineral concentrations in diet formulation is key to a well-formulated diet. Macrominerals typically supplemented in most swine diets include calcium (Ca), phosphorus (P), sodium, and chloride.

- Common ways to describe phosphorus in swine diets are available phosphorus and standardized total tract digestible phosphorus.
- Phosphorus recommendations have been updated for nursery, grow-finish, and gilt development phases based on recent research under commercial conditions.
- Dietary Ca can be described as analyzed (proximate analysis) or total, which is the sum of the analyzed Ca plus the Ca released by phytase.
- Dietary P concentration to maximize bone mineralization is greater than to maximize growth.
- Excess Ca negatively impacts P utilization, particularly when P is limiting; therefore, a ratio of Ca to P should be observed.
- The P concentrations that maximize growth for market pigs may not be the most cost effective. PIC® and Kansas State University developed a tool to help in that decision.
- Sodium requirement is higher for nursery pigs than other stages of production.

Calcium and Phosphorus

Calcium (Ca) and phosphorus (P) are essential for lean tissue deposition, skeleton development and maintenance, and many metabolic functions.

Phosphorus and calcium can be expressed in many ways:

- **Analyzed:** analyzed Ca and P represents all Ca and P that the ingredient contains. This is what you would find in a proximate analysis.
- **Total:** total Ca would be the sum of the analyzed Ca plus the Ca released by phytase.
  - **Bioavailability**
    - Available P is estimated by using a method called "slope-ratio assay." It estimates the digestible plus post-absorptive utilization of these minerals at the tissue level relative to a standard inorganic source; however, this method is more expensive and assumes that an inorganic standard is 100% available.
  - **Digestibility**
    - **Apparent Total Tract Digestibility (ATTD):** estimates the total tract digestibility of Ca and P based on the difference between the amount ingested and the recovered excreted amounts from feces without correcting for basal endogenous losses.
    - **Standardized Total Tract Digestibility (STTD):** estimates the total tract digestibility of Ca and P based on the difference between ingested and recovered amounts from the feces while correcting for basal endogenous losses.
    - **True Total Tract Digestibility (TTTD):** estimates the total tract digestibility of Ca and P based on the difference between ingested and excreted amounts while correcting for both basal and specific endogenous losses.

The NRC (2012) reports the P requirement on a STTD, ATTD, and total basis. The STTD P manner of expressing P is becoming more common among researchers and nutritionists around the world. Establishing the optimum concentration of P on a STTD basis remains an important issue. The NRC (2012) reported the STTD P requirement estimates for nursery pigs based on a mathematical regression model and grow-finish pigs based on a factorial approach. Two recent studies with 1,080 and 2,140 PIC® crossbred pigs have determined that the NRC (2012) accurately estimates the STTD P requirement of 11 to 23 kg pigs on a g/d basis (Vier et al., 2019a). As a percentage of the diet, the STTD P requirement for diets without or with 1,000 FYT added phytase ranged from 0.34 to 0.42% to optimize feed efficiency and growth rate. A recent trial with 1,130 PIC® crossbred pigs indicated that the estimated STTD P concentrations to maximize growth and bone mineralization for 24 to 130 kg pigs were 122% and 131% of the NRC (2012) requirement estimates as a percentage of the diet for mixed gender pigs with mean protein deposition of 135 g/day, respectively (Vier et al., 2019b). The grams of STTD P per kg gain in the nursery and grow-finish phases were 5.77 and 7.50, respectively.

Below are the regression equations used to estimate the PIC® STTD P to calorie ratio requirements based on gender and body weight:

STTD P for Mixed Gender (Barrows and Gilts), g/Mcal of NE = 0.000047 × weight, kg^2 - 0.014391 × weight, kg + 2.027515.

STTD P for Mixed Gender (Barrows and Gilts), g/Mcal of ME = 0.000031 × weight, kg^2 - 0.009664 × weight, kg + 1.476751.

STTD P for Barrows if weight is < 40 kg = the same STTD P:Mcal of mixed gender;
STTD P for Barrows if weight is > 40 kg = g STTD P:Mcal for mixed gender – (-0.0000000031 × weight, kg^4 + 0.0000013234 × weight, kg^3 - 0.0002087068 × weight, kg^2 + 0.0142221655 × weight, kg - 0.3126825057) × g STTD P:Mcal for mixed gender

STTD P for Gilts if weight is < 40 kg = the same STTD P:Mcal of mixed gender;
STTD P for Gilts if weight is > 40 kg = g STTD P:Mcal for mixed gender + (-0.0000000031 × weight, kg^4 + 0.0000013234 × weight, kg^3 - 0.0002087068 × weight, kg^2 + 0.0142221655 × weight, kg - 0.3126825057) × g STTD P:Mcal for mixed gender

STTD P for Boars if weight < 30 kg = the same STTD P:Mcal of Gilts.
STTD P for Boars if weight > 30 kg = g STTD P:Mcal of Gilts + (-0.0000000019 × weight, kg^4 + 0.0000007208 × weight, kg^3 – 0.0000963713 × weight, kg^2 + 0.0050363106 × weight, kg – 0.0486016916) × g STTD P:Mcal of Gilts

STTD P for Developing Gilts = 1.08 × STTD P:Mcal of Gilts

Refer to the PIC® Nutrient Specification Tables for the P requirements in an available and STTD basis. The recommendations for available P are estimated as 86% of the STTD P recommendations in a corn-soybean meal-diet using STTD P coefficient and P bioavailability from NRC (1998 and 2012).

After the minimum P concentrations of the diet are defined, the Ca concentrations are defined as a ratio to P. Several studies have shown that a wide Ca to P ratio is detrimental to pig growth performance and is more evident when P is deficient or marginal (Gonzalez-Vega et al., 2016a,b; Merriman et al., 2017; Wu et al., 2018). However, the optimal ratio between Ca and P could be affected by dietary components, such as phytase. Vier et al. (2019c) reported that the analyzed Ca to analyzed P ratio maximized ADG at 1.38:1 for 26 to 127 kg PIC® pigs fed diets with P in excess of that suggested by NRC (2012) and no added phytase. The optimal ratio increased to 1.63:1 analyzed Ca to analyzed P when phytase was added to the diets at 1000 FYT/kg.

Recent work focuses on defining digestible Ca concentrations from different feed ingredients, which may be used in diet formulation in the future (Stein et al., 2016). A recent trial reported that the Ca to P ratio expressed on a STTD Ca:STTD P basis was more consistent for diets with or without phytase, as compared to the ratio expressed on an analyzed Ca:analyzed P basis (Vier et al., 2019c).

This manual will focus on analyzed Ca. Some ingredients and feed additives may contain Ca sources as a flow agent or carrier. The Ca in these sources are often not accounted for in diet formulation and may have a significant impact on the Ca to P ratio; thus, actual analyzed Ca values may differ from formulated values.

Biological and Economic Models for Optimum Phosphorus Concentration

Dietary P can greatly impact pig growth performance. Phosphorus is considered the third most expensive nutrient in swine diets and has an environmental impact related to its excretion. A study in a commercial setting has demonstrated the STTD P requirement of modern genotypes is greater than NRC estimates as a percentage of the diet for market pigs with mean protein deposition of 135 g/d. It is still similar to NRC for pigs with a greater mean protein deposition of 155 g/d (Vier et al., 2019b). However, the STTD P concentration to support maximal growth will not always result in maximum economic return.

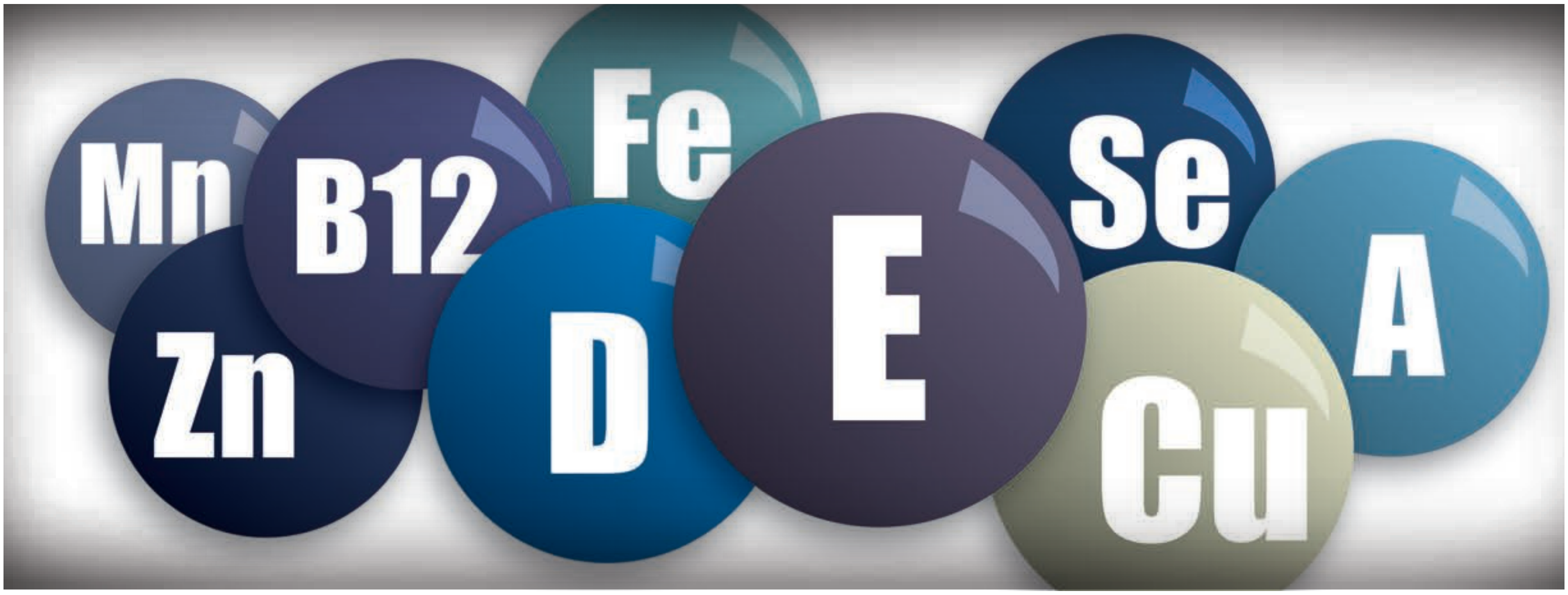
Kansas State University and PIC® developed an Excel-based tool to compare current STTD P concentrations to concentrations required to achieve maximum growth performance, while considering the financial inputs and implications. Click here to access these tools and instructions.

Sodium and Chloride Requirements

Sodium (Na) and chloride (Cl) are important for maintaining water and electrolytes' homeostasis, pH regulation, and nutrient absorption. Greater concentrations of Na and Cl are required by nursery pigs, which is greatly reduced for grow-finish, gestating and lactating sows (NRC, 2012; Shawk et al., 2018; Shawk et al., 2019) The most common source of these ions is added salt (NaCl). Table salt contains approximately 39.5% Na and 59% Cl. Be aware that rock salt, often gray in color, will likely have lower Na and Cl concentrations. A deficiency of Na or Cl can reduce feed intake, average daily gain, and worsen feed efficiency. Salt deficiency can induce tail biting (Fraser et al., 1987). Pigs can tolerate high concentrations of salt provided they have ample access to drinking water. Inadequate water supply in conjunction with high concentrations of salt can induce "salt poisoning". Finally, it is important to monitor Na concentrations in feed ingredients to ensure that the expected formulated concentrations are achieved.

Section E

Trace Minerals and Vitamins



This chapter will discuss minerals and vitamins' supplementation focusing on optimizing performance. Adequate amounts of trace minerals and vitamins in diets are important due to their various roles in regulatory functions. These roles can range from maintaining hoof structure to maximizing reproduction efficiency.

- The vitamin recommendations were updated based on two recent trials under commercial conditions.
- The trace mineral recommendations were adjusted to allow simpler implementation.
- Feeding excess minerals or vitamins can result in toxicity and increased diet cost, whereas feeding inadequate concentrations can result in deficiencies and reduced performance (NRC, 2012; Dritz et al., 2019).

Trace Minerals

Trace minerals commonly supplemented in swine diets include zinc, manganese, iron, copper, iodine and selenium. These specific trace minerals are available in inorganic and organic forms (inorganic forms: sulfates, oxides, chlorides, etc.; and organic forms: chelates, proteinates, etc.) The inorganic forms are most widely used in diets to meet the pigs' requirements.

Beyond concentrations needed for biological requirements, pharmacological concentrations of inorganic zinc (zinc oxide) have been used for nursery pigs to promote gut health and growth. High copper (copper sulfate and tribasic copper chloride) concentration have been used in nursery and grow-finish diets to promote performance. Recent studies showed that sows fed high dietary copper (220 vs. 20 ppm) for multiple parities had improved piglet weight gain. A follow-up nursery trial used their offspring showed the growth-promoting effects of copper might depend on the whole-body copper status (Lu and Lindemann, 2017; Lu et al., 2018). Dietary supplementation of chromium tripicolinate has been reported to improve the litter size of born alive pigs in long-term reproductive female studies that acrossed at least 2 parities, and the mangnitude of response was depending on time and dose of the chromium supplementation (Lindemann and Lu, 2019). Trace mineral supplementation in animal feeds is strictly regulated in some countries due to environmental concerns (Underwood and Suttle, 1999). Ensure that the trace mineral supplementation complies with the local regulations.

As compared to the inorganic source, organic trace minerals are more stable in low pH environments due to the formation of organic ligands. They are expected to have less antagonisms and greater uptake in the small intestines (Leeson and Summers, 2001). The greater digestibility and bioavailability of organic trace minerals allows the producer to achieve similar or improved performance with reduced inclusion rates (Richards et al., 2010; Liu et al., 2014). Some studies have shown organic trace minerals could boost immune response, alleviate oxidative stress, enhance bone development and strength, and improve sow reproductive performance (Peters and Mahan, 2008; Richards et al., 2010; She et al., 2017; Liao et al., 2018). However, these responses have been inconsistent, a majority of pigs are fed inorganic trace minerals in North America (Flohr et al., 2016). One exception is organic selenium, which has a broader acceptance especially in sow and boar diets.

Vitamins

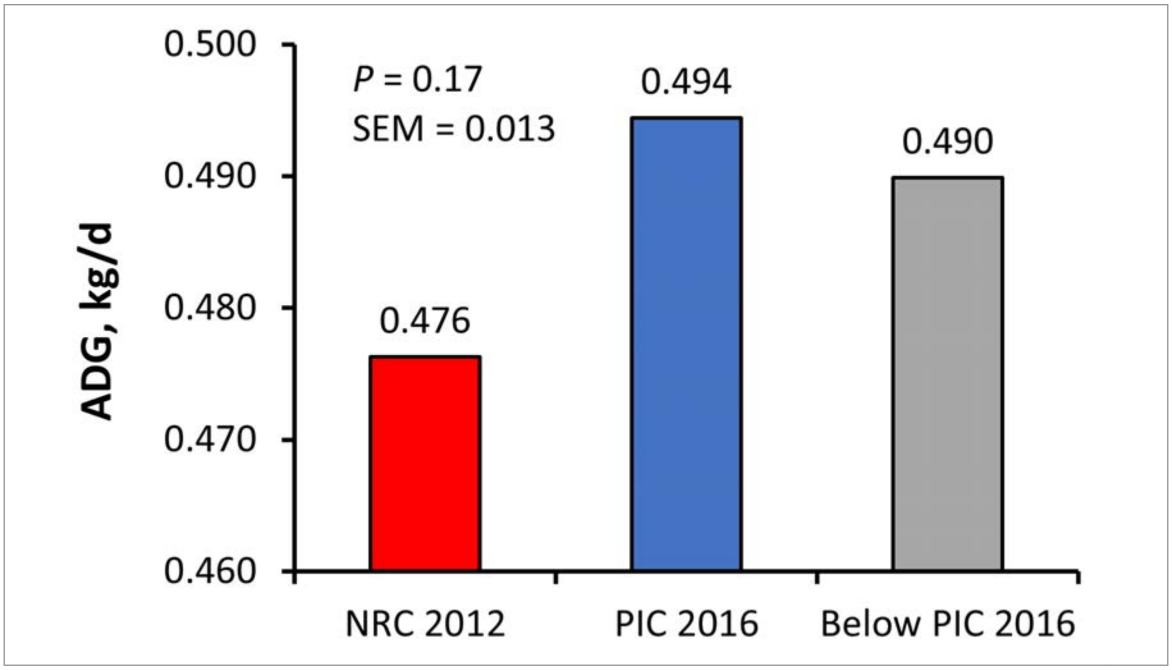
Vitamins play critical roles (as coenzymes) in various metabolic pathways of normal growth and reproduction. Proper concentrations of vitamin supplementation are important to optimize performance and minimize unnecessary costs. Vitamins are commonly added to commercial diets at concentrations exceeding the NRC (2012) requirement estimates. A survey compared current supplemental vitamin feeding regimens of the US swine industry to the NRC requirement estimates (Flohr et al., 2016). Results showed fat-soluble vitamins were added at rates of 4.0 to 11.6 times in nursery diets and 1.8 to 6.7 times higher in grow-finish diets. Other vitamins were added at rates 0.4 to 7.1 times in nursery and 0.7 to 3.8 times in grow-finish diets. A recent study evaluated vitamin concentrations supplemented in a commercial wean-to-finish program with 1,200 PIC® pigs (PIC® 337 × Camborough®; Thompson et al., 2020).

Treatments consisted of added vitamins from the premix without accounting for those in ingredients (Table E1):

1. NRC 2012: added vitamin concentrations identical to NRC (2012) recommendations;
2. PIC® 2016: added vitamin concentrations identical to PIC® (2016) recommendations; and
3. Below PIC® 2016: added vitamin concentrations below PIC® (2016) recommendations.

Table E1. Added Vitamin Concentrations (per kg of complete diet) for Pigs from 5 to 130 kg for the Three Treatments (Thompson et al., 2020).

Treatment	NRC 2012		PIC® 2016			Below PIC® 2016		
Bodyweight range, kg	5-25	25-130	5-25	25-80	80-130	5-25	25-80	80-130
Vitamin A, IU	2,200	1,300	11,025	6,615	5,510	4,200	2,800	2,800
Vitamin D3, IU	220	150	1,765	1,215	1,015	1,600	800	640
Vitamin E, IU	16	11	85	33	28	16	11	11
Vitamin K, mg	0.5	0.5	5.5	3.3	2.8	3.0	1.5	1.2
Thiamin, mg	1.0	1.0	3.5	---	---	---	---	---
Riboflavin, mg	3.5	2.0	13.0	5.7	4.9	8.0	4.0	3.0
Pyridoxine, mg	7.0	1.0	3.5	---	---	---	---	---
Vitamin B12, µg	17.5	5.0	55.0	26.0	22.0	39.0	19.0	15.0
Niacin, mg	30	30	70	40	31	50	25	20
d-Pantothenic acid, mg	10	7	40	20	17	28	14	11
Folic acid, mg	0.30	0.30	1.05	---	---	---	---	---
Biotin, mg	0.050	0.050	0.275	---	---	---	---	---



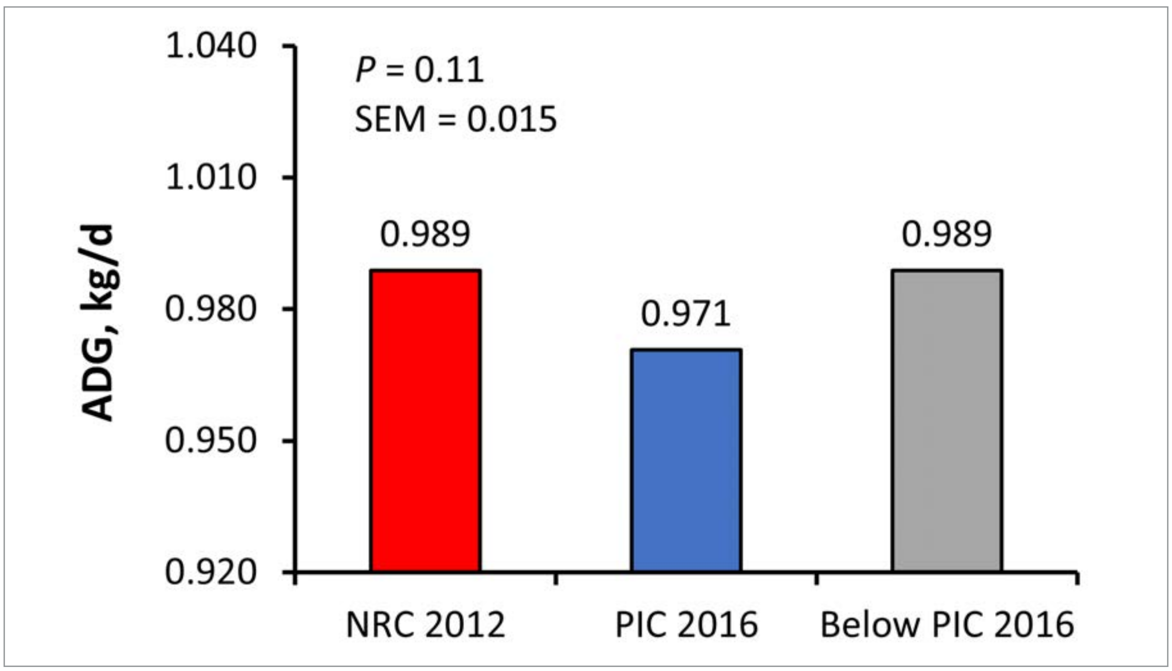


Figure E1. Effects of Different Added Vitamin Concentrations on Growth Performance of Nursery (top) and Grow-finish (bottom) Pigs (Thompson et al., 2020)

In the nursery and grow-finish periods (5 to 128 kg), there was no evidence of differences in growth rate, feed intake, and feed efficiency among treatments (Figure E1). Tuffo et al. (2019) reported similar results, with no evidence for differences on the overall growth performance of grow-finish pigs (16 to 125 kg) fed low or high vitamin supplemented diets. In addition, the added vitamin concentrations in Tuffo's low vitamin diets were similar to those in the Below PIC® 2016 diets. Therefore, PIC® lowered the recommended concentrations of supplemental vitamins based on these two most recent trials and adjusted the trace mineral recommendations to allow simpler implementation. Although, there was no evidence of difference from the NRC concentrations we recommend using a margin of safety to account for losses under a wide variety of conditions.

Section F

Mature Boar

Boar feeding program objectives are to promote adequate growth, maximize reproductive performance, maintain structural soundness and enhance longevity.

- Feeding guidelines are based on body weight with adjustments for body condition and environment.
- The PIC® Optimum Boar Feeding tool calculates recommended nutrient levels for boars during quarantine and production.
- Feeding management is important for the success of a boar feeding program.

Boar Feeding

Boars are not only a source of genetic improvement but also influence farrowing rate and litter size. They represent a small part of the population, and research to make specific recommendations on boar diet nutrient content is relatively scarce. Boar feed is a small percentage of the total feed needed by a production system. There is little understanding of the boar's precise nutrient needs. Thus many vitamins and trace minerals are provided with large margins of safety. Use caution because excesses can be detrimental to performance. The nutrient recommendations for boars are presented in the nutrition specification tables. These recommendations are used by PIC®s studs and are given for reference.

The influence of a boar's nutritional status on reproductive performance is measured by libido, semen output, viability, and fertilization capacity of the sperm cells (semen quality). Suggested energy and amino acid levels are based on limited research. The energy and amino acid nutrition effects on boar reproductive performance have been measured by Stevermer (1961), Kemp et al. (1989), Close and Roberts (1993), Louis et al. (1994a,b).

Feeding During Quarantine

Before semen collection, boars are received and housed in a quarantine barn for approximately 30 to 35 days, usually in individual stalls or pens. Estimate the feeding level by the energy requirement for maintenance and body weight gain (ARC, 1981; Close and Roberts, 1993). Table F1 shows the feeding levels for boars during quarantine estimated by the PIC® Optimum Boar Feeding Tool (Please click here). The first few days in quarantine feed intake will be lower due to transportation stress. Do not feed more than 2.3 kg for the first few days after arrival, then gradually increase to the desired feeding level by the end of the quarantine.

Feeding When in Production

Feed intake levels for mature boars depend on both body weight and body condition. Maintenance, body weight gain, and semen collection and production indicate the boars' energy requirement which dictates feeding level (ARC, 1981; Close and Roberts, 1993; Kemp et al., 1990). Table F1 gives a base recommended feeding level for boars based on body weight and depending on the season. Make adjustments to the levels indicated in Table F1 to achieve the desired body condition score (Levis, 1997). Feed thin boars an additional half kilogram over the desired level, and feed fat boars a quarter kilogram below the desired level shown in Table F1. An adult boar's thermoneutral temperature is 17°C (Stähr et al., 2009). Adjust feed to compensate for boars housed below thermoneutral temperature. Please refer to PIC® Boar Stud Management Guidelines for more information on body condition scoring, click here.

Table F1. Feeding Level for Boars in Quarantine and Production[a]

Body Weight, kg	Warm Season			Cold Season		
	ME, Mcal/day[b]	NE, Mcal/day[c]	Feeding Level, kg/day	ME, Mcal/day[b]	NE, Mcal/day[c]	Feeding Level, kg/day
Quarantine[d]	8.3	6.2	2.6	8.6	6.4	2.7
180	7.9	6.0	2.5	8.3	6.2	2.6
212	7.9	6.0	2.5	8.6	6.4	2.7
244	8.3	6.2	2.6	8.6	6.4	2.7
276	8.6	6.4	2.7	8.9	6.7	2.8
308	8.9	6.7	2.8	9.5	7.1	3.0
340	9.5	7.1	3.0	10.2	7.6	3.2

[a]Assuming ambient temperature in warm season is 17°C and above, whereas 15°C in cold season. Based on a dietary energy density of 3175 Kcal ME/kg.
ME = metabolizable energy; NE = net energy.

[b]Daily ME requirement is estimated by the following models:

ME for maintenance = 0.1832 × $(\text{Body weight, kg})^{0.665}$, Mcal/d

ME for growth = 4.89 × (Body weight gain per day, kg), Mcal/d

ME for sperm production = 0.1 Mcal/d

ME for each degree below 17 degrees Celsius for individually housed boars on slatted floor
= 0.00382 × $(\text{Body weight, kg})^{0.75}$, Mcal/degree/d

ME for mating activity = 0.0043 × $(\text{Body weight, kg})^{0.75}$, Mcal/d

[c]Assuming NE to ME ratio at 0.75.

[d]ME requirement during quarantine considers only ME for maintenance and growth.

Consumption of feed contaminated with mycotoxins can negatively influence boar reproductive performance. Semen ejaculate volume and sperm motility were reduced for boars greater than 10 months old fed diets contaminated with 0.57 ppm of zearalenone compared to boars fed mycotoxin-free feed (Sutkevičienė et al., 2009). Moreover, libido of young and mature boars is reduced due to a decrease in testosterone when fed diets contaminated with zearalenone (Berger et al., 1981; Ruhr et al., 1983).

Protein intake has not shown an effect on semen quality. Low protein intake can result in a reduction in libido and semen volume as demonstrated by Louis et al. (1994a, b). According to Kemp et al. (1988), increasing the dietary protein level above levels fed to gestating sows (14.5% CP with 0.68% Lys) did not benefit sperm production. In general, feeding 0.62% SID Lys seems to be enough to support mature boar reproductive performance. Younger boars (< 11 months of age) may have improved reproductive performance with higher Lys levels. Recommended dietary zinc concentrations range from 100 to 150 ppm. The use of an organic form of zinc above the recommended levels did not improve semen quantity or quality (Althouse et al., 2000). Although no experimental data are available, biotin is often added at 200-300 mg/ton (Tokach and Goodband, 2007). There is some evidence that 0.3 ppm of organic selenium may help maintain sperm motility after consecutive collections, help reduce the negative effects of semen storage on semen motility, and improve in vitro fertilization rates (Speight et al., 2012).

The impact of super dosing phytase is not clear. In a study conducted by Stewart et al. (2016), the authors reported that super dosing phytase (2000 FTU/kg of diet; Quantum® Blue) resulted in 11% increase in semen doses produced per boar per year. However, in another super dosing phytase trial (500, 2000, and 3000 FTU/kg of diet; Quantum® Blue), there was no evidence for differences in total sperm count and semen doses produced (Moreira et al., 2016). Further investigation is needed.

Omega-3 fatty acids, including linolenic, eicosapentaenoic, and docosahexaenoic, appear to positively impact boar semen quality. Sufficient quantities of eicosapentaenoic and docosahexaenoic can be metabolized from linolenic acid. An increase of 11% in total sperm cells per ejaculate has been reported in boars being fed for 16 weeks with 0.29 kg/d of a top-dressed supplement containing 31% omega-3 fatty acids (Estienne et al., 2008). A recent study has reported a marginally significant increase in total sperm production of 6% for boars fed 16.3 g of a product with 96% betaine during summer months (Cabezón et al., 2016). Another recent study has suggested that supplementation of 0.8 to 1.0% L-arginine improved semen quality and libido during hot summer months (Chen et al., 2018).

Additionally, boars supplemented with L-carnitine at 500 mg (Baumgartner, 1998) or 230 mg (Wähner et al., 2004) demonstrated increased sperm volume and concentration. Data from Kozink et al. (2004) did not support these effects in the young boar. Jacyno et al. (2007) supplemented 500 mg of L-carnitine per day and observed improvements on semen quality related to ejaculate volume, concentration, morphological abnormalities of the sperm and activity of aspartate aminotransferase. More research is warranted to validate these findings.

Optimum Feeding Level for PIC® Boars

Boars are the source of genetic improvement, and the performance of boars also affects farrowing rate and litter size. Feeding boars to their body condition is critical to optimize performance and longevity. The PIC® Optimum Boar Feeding Tool estimates optimum feeding levels for boars in quarantine and production, which balances diet energy level, boar body weight, boar weight gain, collection intensity, and ambient temperature. It helps production supervisors and nutritionists to create a tailored boar feeding program that matches production reality. Click here to access this tool through computers, smartphones or tablets.

Developing Gilt

When feeding developing gilts to maximize lifetime productivity, the goals are adequate growth rate, sufficient mineral stores and bone development, reproductive tract maturation, and sound foot and leg structure.

- Gilt breeding eligibility targets are:
  - Age at puberty: Less than 195 days of age.
  - Age: 200 to 225 days.
  - Body weight: 135 to 160 kg.
  - Estrus: 2^{nd} estrus (3^{rd} only if <135 kg).
  - Lifetime average daily gain of 600 to 800 g/d, with increased bone stores and vitamin fortification specific for reproduction.
- Differences between gilt development diet and market gilt diet.
- These gilt targets are important for improving lifetime productivity and reducing lifetime total feed cost.

Targets for Gilt Development

Gilt development and management begin in the early stages of a gilt's life and ends when the gilt completes her first lactation (Boyd et al., 2002). Consider multiple factors to achieve a successful gilt development program. Age at puberty, age, weight, and number of estruses at first breeding are key elements for the long-term success of the gilt pool and the sow herd (Table G1).

Gilts should achieve puberty at less than 195 days of age. The ideal age range for breeding is between 200 to 225 days, with a weight range of 135 to 160 kg bodyweight and at 2nd estrus (3rd only if light). Gilts below 135 kg are too light and should not be bred as they are prone to reduced prolificacy. Avoid breeding gilts over 160 kg should due to the elevated maintenance cost, more lactation weight loss, increased chances of locomotor problems, and a higher rate of early culling. To achieve both age and weight targets for gilts at first breeding, the lifetime average daily gain from birth to the first service is between 600 to 800 g/day. Please refer to PIC® Gilt Development Guidelines (Please click here) for detailed information.

Table G1. Targets for Developing Gilts at First Breeding

Trait	Target
Estrus at first service	
Minimal	2
Body weight	
Too light, do not breed	< 135 kg
Eligible to breed	135-160 kg
Too heavy	> 160 kg
ADG from birth to first breeding, g/d	
Minimal	600
Maximal	800
Age at first breeding, days	
Minimal	200
Maximal	225
Age at puberty, days	
Younger than	195

Gilt Feeding Recommendations

To meet the gilt targets at first breeding, PIC® recommends *ad libitum* feeding from birth to the first breeding. The Lys to calorie ratio for developing gilts is adopted from the recommendations for PIC® market gilts. Dietary energy level can be used to regulate growth rate. Maximizing bone mineralization is one of the primary goals for gilt development. Feed developing gilts Ca and P levels greater than grow-finish pigs (Whitney and Masker, 2010). Based on a recent trial with PIC® market pigs (Vier et al., 2019b), recommended phosphorus concentrations for developing gilts are approximately 8% greater than the commercial gilt recommendations to maximize bone mineralization.

As a summary, key differences of a gilt development diet comparing to a market gilt diet are:

1. Greater Ca and P levels.
2. Increased vitamin and trace mineral levels.
3. Addition of vitamins specifically required for reproduction (pyridoxine, folic acid, biotin).

For more detailed nutrient specifications for developing gilt, refer to Section N: PIC® Nutrient Specifications for Developing Gilts (As-Fed).

Producers without feed mill capacity to manufacture a series of specialized gilt development diets can take advantage of existing diets to reduce diet types. Table G2 gives examples of options for developing gilt feeding programs.

Table G2. Examples of Feeding Programs for Developing Gilts

Body Weight of Developing Gilts, kg		
23 to 60	**60 to 90**	**90 to breeding**
Use GDU[a] specific diet or either the commercial gilt diet or the lactation diet.	Use GDU specific diets. One or more diets maybe used within this weight range.	Use a GDU specific diet or the gestation diet which is typically used in many farms.

[a]GDU = Gilt developing unit.

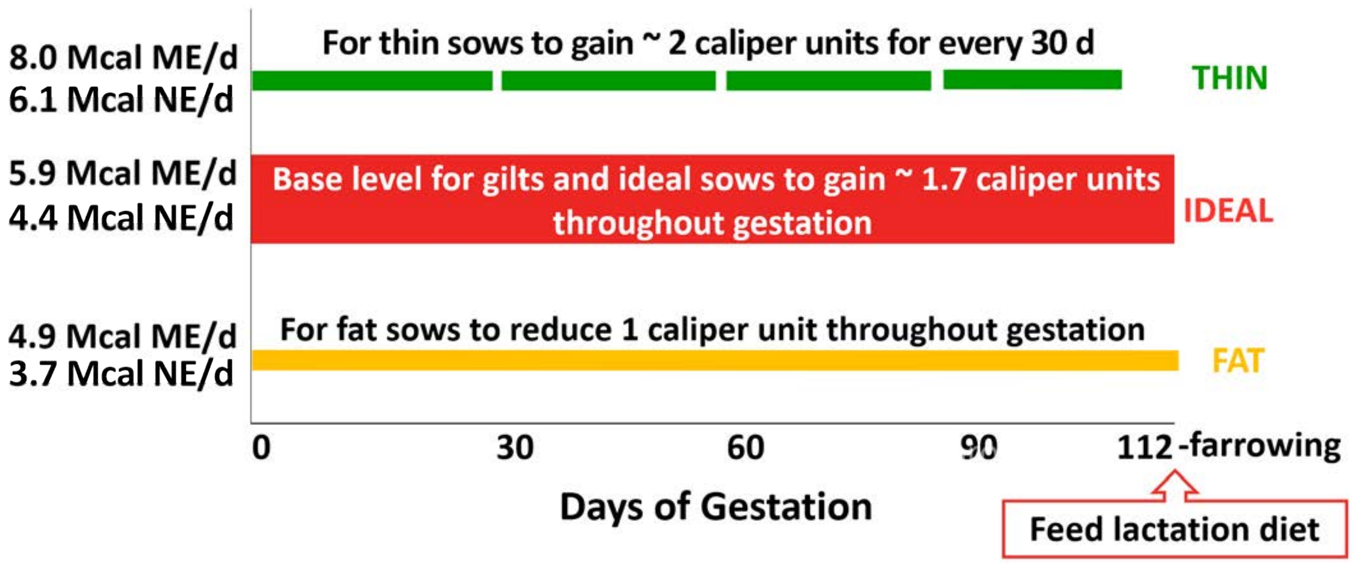
For further information about the management of the developing gilt, please click here for the PIC® Gilt and Sow Management Guidelines.

Section H

Gestating Gilt and Sow

During gestation, the feeding goal is to manage body condition and have an adequate nutrient supply for maternal maintenance, growth, and development of the placenta, mammary tissue, uterus, and conceptus.

- Body condition management:
  - Body condition determines the desired feeding levels during gestation.
  - Use a caliper to score and maximize the number of sows in ideal body condition at farrowing.
- Early gestation:
  - Do not feed under maintenance and do not feed over two times of maintenance or over 10 Mcal of ME/d.
  - Check individual feed intake, mainly for gilts and parity 1 sows, in the first few days after being group-housed and fed through electronic sow feeding systems.
  - If aggressive behavior is observed right after grouping, consider providing increased feed per sow or gilt with a maximum of 3 kg/d for no longer than five days.
- Late gestation:
  - Obtain caliper reading and feed according to body condition as recommended. If unable to obtain it, maintain feeding level from previous periods.
- Peripartum:
  - Feed lactation diet the same level as sows were fed in gestation.
  - Increased feeding frequency has been shown to reduce stillborn rate when farrowing assistance is limited.



The estimated caliper score change is based on a sow herd assuming an average body weight of 200 kg. The regression equation was reported by Knauer et al., (2020): caliper score change per day = 1.35 × (ME intake, Mcal/d) ÷ (Body weight, kg)$^{0.75}$ – 0.1332.

Figure H1. PIC® Feeding Recommendations for Gilts and Sows During Gestation

Sow Body Condition Management

- Body condition of sows is associated with subsequent reproductive performance
- Minimize thin sows at farrowing, fat sows at weaning, and maximize ideal sows at farrowing as much as possible
- Use body condition as guidelines for gestation feeding

A key aspect of a high-performance sow farm is to manage sow body condition properly. The goal is to maintain well-conditioned sows, and to avoid having any thin sows at farrowing and fat sows at weaning (Figure H2). Several methods are available for the estimation of sow body condition, including visual scoring, backfat, and the caliper. PIC® recommends using the caliper to assess sow body condition. Click here to access the most updated technical material of sow body condition management.

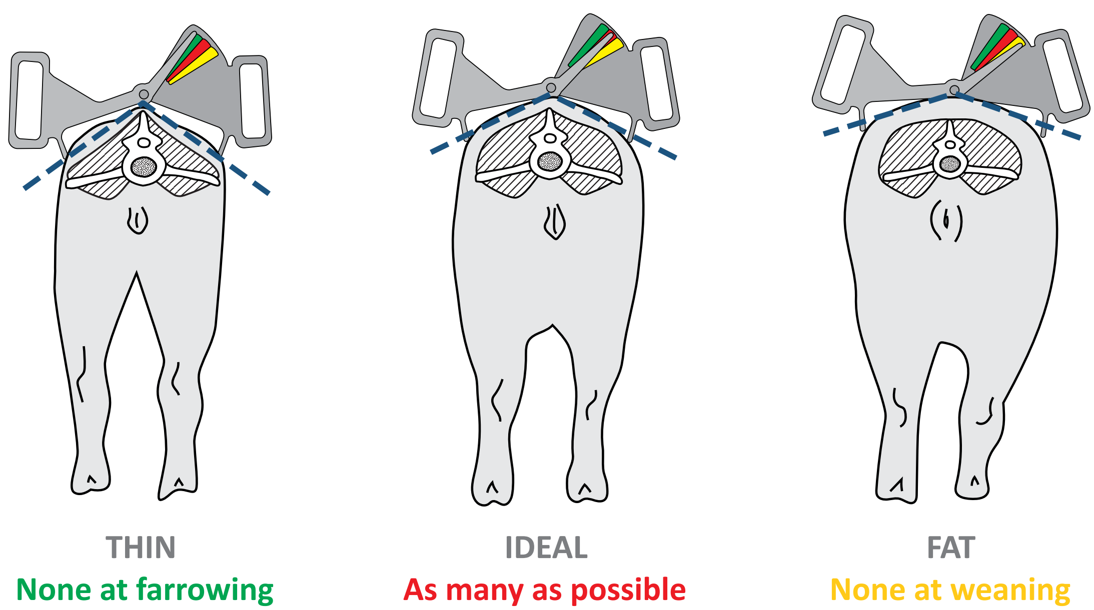
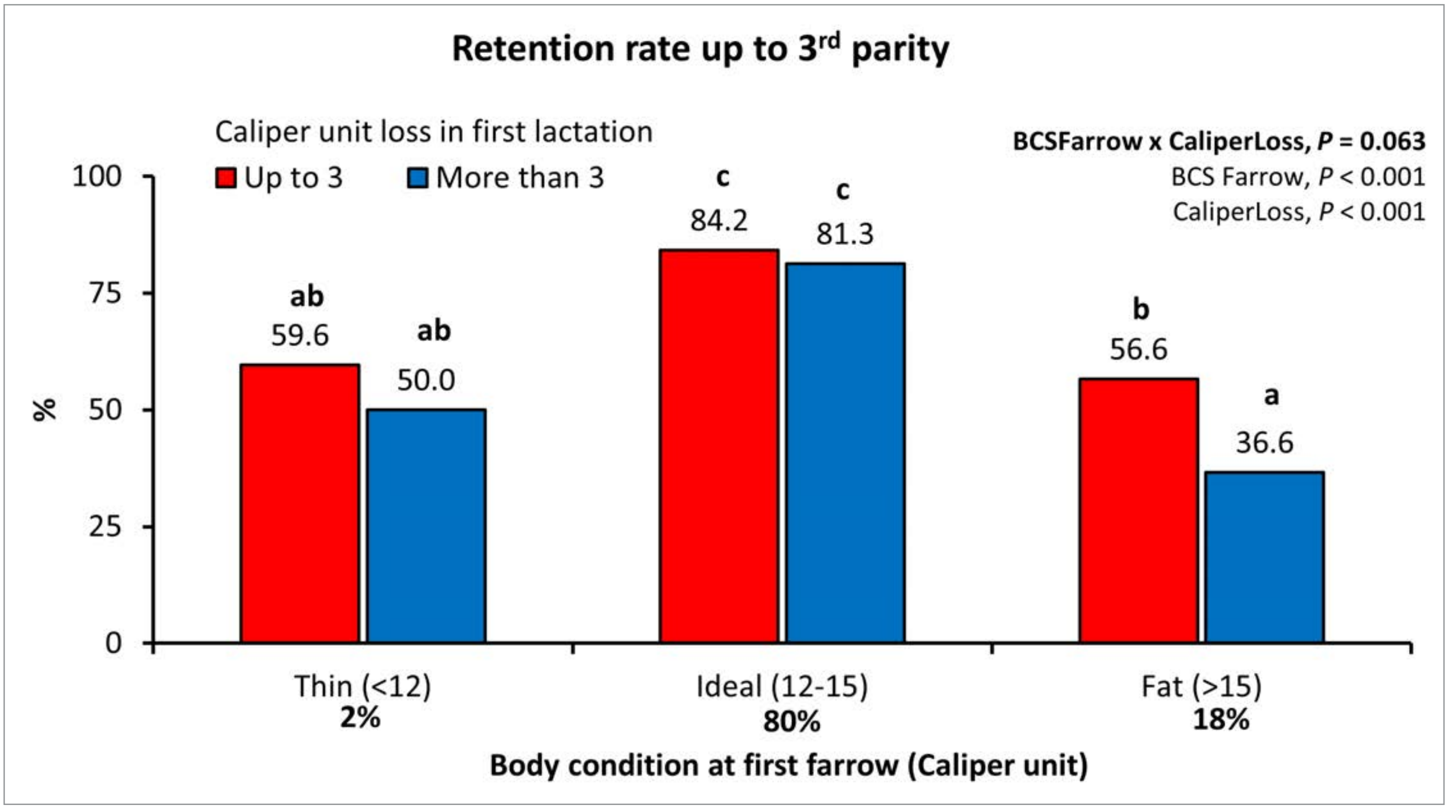


Figure H2. Sow Body Condition Measurement Using a Sow Caliper

Globally our technical service teams commonly observe over-conditioned sows at farrowing. Fat sows are costly from a feed perspective and because they have poorer lactation performance and compromised subsequent performance. Voluntary feed intake during lactation is decreased when sows are over-conditioned at farrowing, resulting in greater body weight loss, lower milk production, and potentially lighter piglet weights at weaning. This negative energy balance during lactation will likely result in a subsequent reduced litter size. Moreover, an observational study on approximately 4,500 gilts indicated that their body condition at first farrow and body condition change during the first lactation is associated with longevity (Huerta et al., 2021, Figure H3). Gilts in ideal condition at first farrowing had greater retention rate up to 3rd farrowing compared to thin and fat gilts. The retention rate was further reduced for fat gilts as caliper unit loss during lactation increased, with approximately 60% of the gilts in the database losing over 3 caliper units. This emphasizes the importance of properly maintaining gilts and sows in ideal body condition to improve feed savings and maximize reproductive performance.



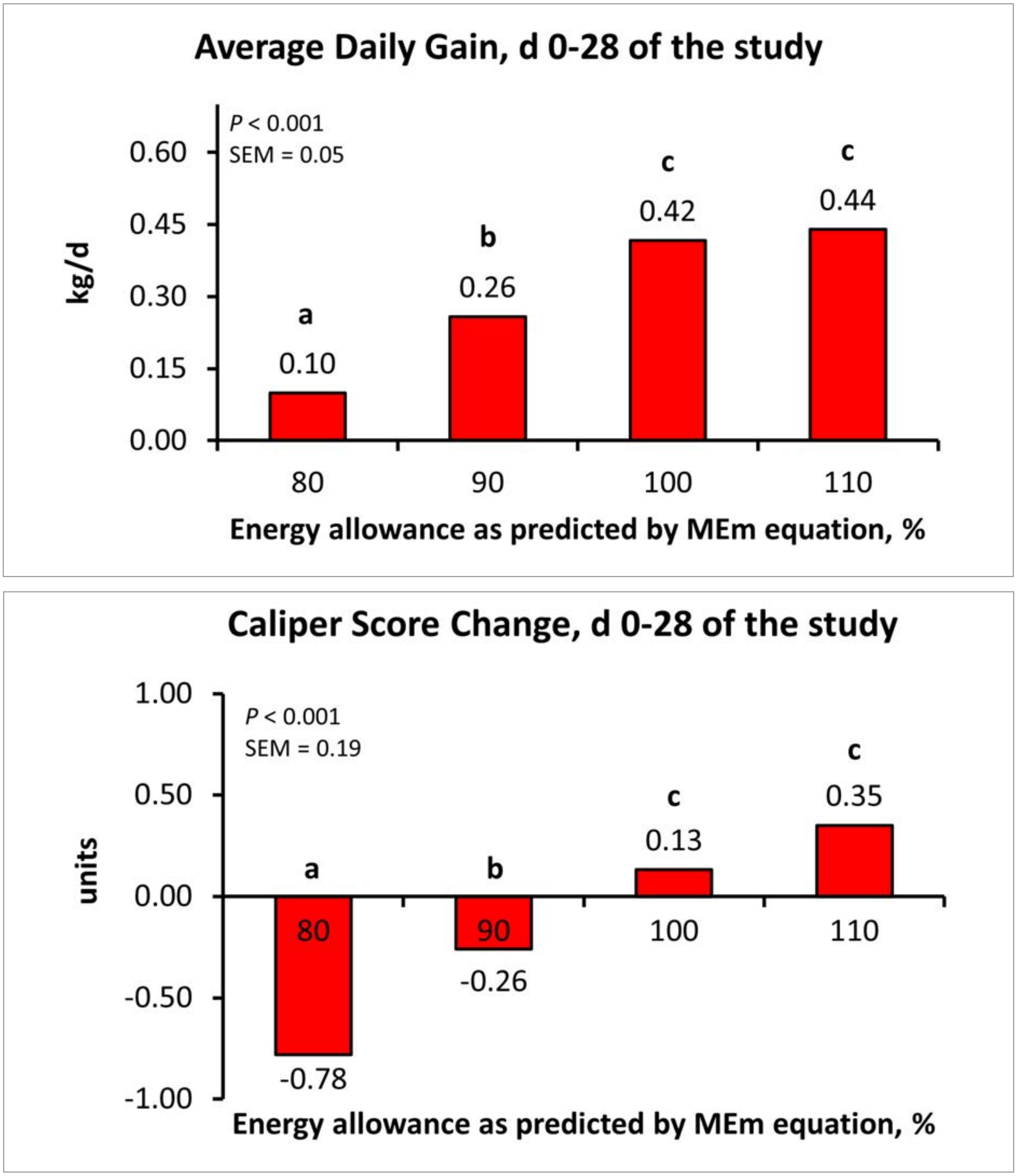
[a,b,c]Bar means without common superscript differ, P < 0.10.

Figure H3. Retention Rate up to Third Parity According to Gilt Body Condition at First Farrowing and Body Condition Change during Lactation (Huerta et al., 2021)

The breeding goals of PIC® maternal lines have changed over time. Besides reproductive traits, approximately 40% of the terminal line traits such as grow-finish survival and robustness, efficiency of growth, and carcass traits are also included in the maternal line traits. As a result, the modern PIC® Camborough® sow is more efficient than in the past.

A recent study evaluated the NRC (2012) model in predicting the standard maintenance metabolizable energy (ME_m) requirement of PIC® sows during mid-gestation (Knauer et al., 2020). In this study, 200 Camborough® sows were fed 80, 90, 100, or 110% of ME_m according to the NRC (2012) equation ME_m, kcal/d = 100 × (body weight, kg)$^{0.75}$. Sows started on trial between day 36 and 46 post-breeding and were fed a corn-soybean meal-based diet with 3,302 kcal ME/kg and 0.61% SID Lys for 28 days.

Results showed that the ME_m to maintain body weight and sow body condition caliper score were below 80% and 98.7% of the NRC (2012) ME_m requirement estimates, respectively (Figure H4). Even though sows in all the treatments had positive average daily gain during this period, there is an increase in accumulation of embryonic fluid between d 40 and 60 of gestation, which could be influencing gain (Bazer et al., 2012). Results showed that the NRC (2012) model only slightly overestimates the ME_m requirement of Camborough® sows during mid-gestation. The information obtained in this trial was used to create the current feeding recommendations for gilts and sows throughout gestation.



[a,b,c]Bar means without common letter differ, $P < 0.05$.

Figure H4. Average Daily Gain (Top) and Caliper Score Change (Bottom) of Sows Fed 80, 90, 100, or 110% of Maintenance Metabolizable Energy (MEm) According to the NRC (2012) Equation, MEm, kcal/d = 100 × (Body Weight, kg)$^{0.75}$, for 28 Days Starting Between d 36 and 46 of Gestation (Adapted from Knauer et al., 2020)

Early-Gestation Feeding

- Do not feed under maintenance energy requirement.
- Do not feed over two times maintenance energy requirement or over 10 Mcal of ME/d.

Effects of different feeding levels in early gestation on embryo survival, plasma progesterone and subsequent total born of gilts and sows from different studies are summarized in Table H1. In the past, high feed intake after breeding was associated with lower embryonic survival, thus sow feed intake was limited (Jindal et al., 1996). Contrarily, recent studies have demonstrated lower embryo survival and litter sizes for females that were restrict fed (Athorn et al., 2013; Langendijk et al., 2017). In a recent study, Mallmann et al. (2020) found that thin parity 1 sows responded to intermediate feeding levels from d 6 to 30 of gestation (5.7 vs. 7.8 Mcal ME/d; 108 vs. 150% of maintenance) as demonstrated by increased total born. The authors observed a reduction in piglet throughput for gilts and sows fed over 10 Mcal ME/d.

In group housing with electronic sow feeding systems monitor individual animal feed intake. Especially for gilts and parity 1 sows in the first few days after grouping. Also, if aggressive behavior is observed right after grouping consider providing increased feed per sow or gilt with a maximum of 3 kg. Research suggests aggressive behavior decreases after the first few days after mixing. Thus, ensure the increased feed allotment is provided for no longer than five days to prevent excess sow weight gain.

Table H1. Descriptive Summary of Experiments Evaluating the Impact of Different Feeding Level During Early Gestation on Embryo Survivability, Plasma Progesterone, and Subsequent Total Born of Gilts and Sows

Reference	Gestation days	Weight at breeding, kg	ME_m, Mcal/d	Feeding level, kg/d		% of ME_m		Response criteria		
				CON.	TRT.	CON.	TRT.	Embryo survivability	Plasma progesterone	Total born
Jindal et al., 1996[a]	1 – 15	116	3.52	1.91	2.59	146%	200%	-22%	-57%	---
De et al., 2008[a]	1 – 35	---	---	---	---	120%	200%	-20%	-14%	---
Athorn et al., 2013[a]	0 – 10	126	3.76	1.50	2.82	115%	215%	19%	26%	---
Langendijk et al., 2015[a]	10 – 11	103	3.22	0.00	2.50	0%	223%	---	-8%	24%
Virolainen et al., 2005[b]	1 – 35	252	6.32	2.00	4.00	89%	179%	-35%	-25%	---
Hoving, 2012[b]	3 – 35	170	4.71	2.50	3.32	165%	215%	2%	ns	
Mallmann et al, 2020[b]	6 – 30	197	5.26	1.82	2.50	108%	150%	---	---	0%
Mallmann et al, 2020[b]	6 – 30	197	5.26	1.82	3.23	108%	192%	---	---	-8%
Weighted Averaged	**---**	**185**	**5.00**	**1.82**	**2.91**	**111%**	**180%**	**-12%**	**-24%**	**-2%**

[a]The trial was conducted with gilts only.

[b]The trial was conducted with sows only.

Late-Gestation Feeding

- Continue to feed according to body condition.
- Maintain feeding level from the previous period if unable to get a caliper reading.

The NRC (2012) suggests that each piglet increase results in an increase of approximately 0.10 and 0.35 g of SID Lys required per day from day 1 to 90 and day 90 to 114 of gestation, respectively. Thus, nutrient requirements have not changed enough to have a dramatic requirement update. Multiple studies were unable to increase gilt and sow reproductive performance by increasing feed intake (Ampaire and Levesque, 2016; Buis et al., 2016; Gonçalves et al., 2016b; Greiner et al., 2016; Mallmann et al., 2019). This seems to indicate that even though the requirements change during the course of gestation the sow is resilient at mobilizing body tissues at a relatively wide range of nutrient intake. Therefore based on the practical realities in most production systems, feeding a single gestation diet and a flat feeding amount for sows in ideal body condition has the advantage of being simpler to manage in the farm.

Studies that evaluated increased feed intake in late gestation for gilts or sows are summarized in Table H2 and H3. The data shows a body weight (BW) increase by approximately 7.7 and 8.9 kg, respectively when gilts and sows are bump fed an extra 1 kg/d during late gestation. The effect of bump feeding on piglet birth weight was modest for gilts (12.0 g) and minimal for sows (-1.3 g).

Table H2. Descriptive Summary of Experiments Evaluating the Impact of Increased Feed Intake During Late Gestation on Gilt Body Weight Gain and Piglet Birth Weight

Reference	Start, day of gestation	Litters per treatment, n	Total born, n	Control, Mcal ME/day	Control, g SID Lys/day	Increased feed intake, Mcal ME/day	Increased feed intake,g SID Lys/day	Increased by treatment	
								Female BW gain, kg/ kg of extra daily feed	Piglet birth weight, g
Shelton et al., 2009	90	21	14.3	6.8	11.9	9.8	17.1	6.6	86
Soto et al., 2011	100	24	12.5	7.0	9.87	12.9	18.2	NR	126
Goncalves et al., 2016	90	371	14.2	5.9	10.7	8.9	10.7	5.6	24
Goncalves et al., 2016	90	371	14.2	5.9	20.0	8.9	20.0	9.1	28
Greiner et al., 2016	100	65	13.4	5.9	9.0	8.8	14.0	NR	-120
Ampaire and Levesque, 2016	90	17	13.4	7.2	12.3	8.6	14.5	24	-10
Mallmann et al., 2018	90	50	14.4	5.9	11.7	7.2	14.3	6.5	6
Mallmann et al., 2019	90	243	14.1	5.9	11.5	7.6	14.7	6.4	26
Mallmann et al., 2019	90	242	14.3	5.9	11.5	9.2	17.9	8.8	-1
Mallmann et al., 2019	90	246	14.3	5.9	11.5	10.9	21.1	7.9	-11
Weighted Average[a]	---	---	**13.9**	**6.0**	**12.0**	**9.3**	**16.3**	**7.7 ± 2.4**	**12 ± 36.1**

Table H3. Descriptive Summary of Experiments Evaluating the Impact of Increased Feed Intake During Late Gestation on Sow Body Weight Gain and Piglet Birth Weight

Reference	Start, day of gestation	Litters per treatment, n	Total born, n	Control, Mcal ME/day	Control, g SID Lys/day	Increased feed intake, Mcal ME/day	Increased feed intake,g SID Lys/day	Increased by treatment	
								Female BW gain, kg/ kg of extra daily feed	Piglet birth weight, g
Shelton et al., 2009	90	32	12.4	7.9	11.9	11.4	19.9	4.9	-109
Soto et al., 2011	100	51	12.9	7.9	11.2	13.9	19.5	NR	-69
Goncalves et al., 2016	90	181	15.1	5.9	10.7	8.9	10.7	9.0	47
Goncalves et al., 2016	90	181	15.3	5.9	20.0	8.9	20.0	10.8	19
Greiner et al., 2016	95	128	14.7	5.9	9.0	8.8	14.0	7.1	-40
Mallmann et al., 2018	90	221	15.4	5.9	11.7	7.2	14.3	9.0	-4
Weighted Average[a]	---	---	**14.3**	**6.6**	**12.4**	**9.9**	**16.4**	**8.9 ± 1.6**	**-1.3 ± 44.2**

[a]Weighted based on the number of litters in each study.

PIC® stopped recommending bump feeding in 2016 for sows but not for gilts. According to Goncalves et al. (2016), bump feeding only resulted in minimal improvements in piglet birth weight and increased stillbirth rate by 2.1% in sows bump fed compared to sows not bump fed. However, the increased stillbirth rate was not observed in gilts (Figure H5). In addition, energy was the driver of the modest increase in PIC® piglets' birth weight rather than amino acid intake (Gonçalves et al., 2016).

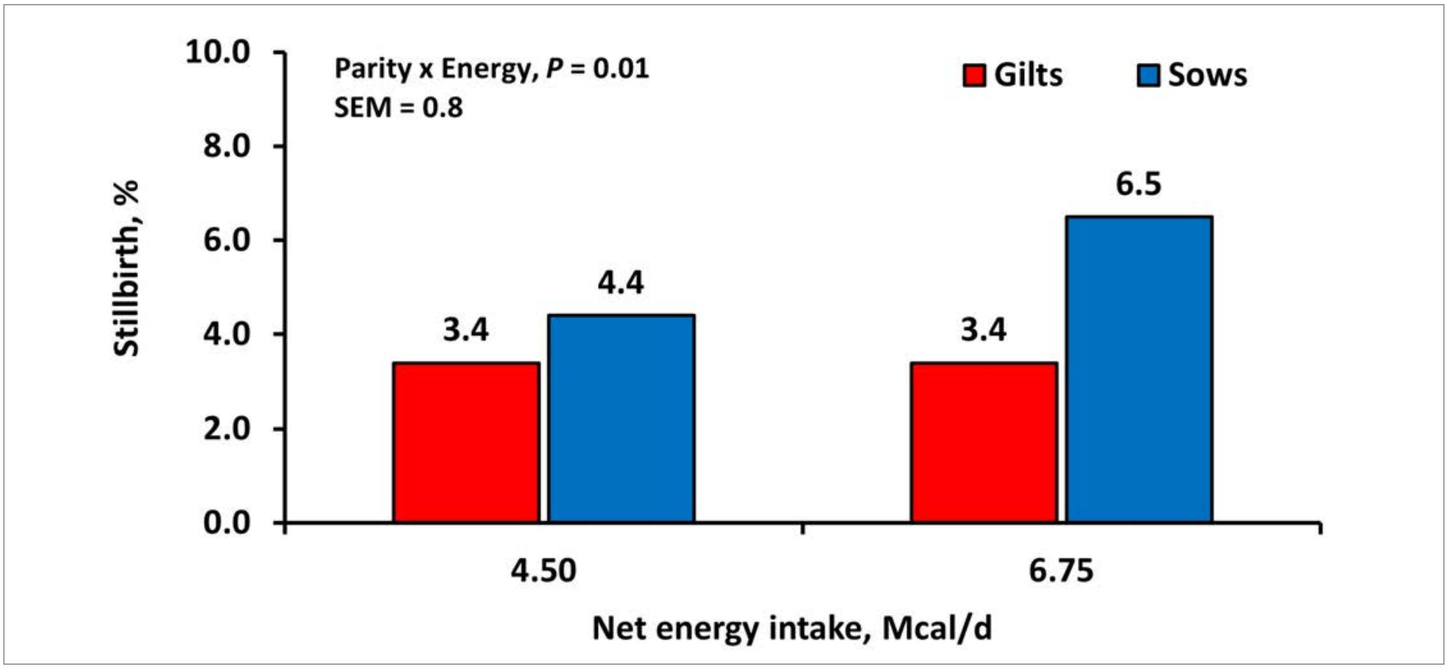


Figure H5. Bump Feeding can Increase 2.1% Stillborns in Sows, but not in Gilts (Gonçalves et al., 2016)

A recent trial using 977 gilts with body condition score between 2.5 and 4.5 showed increasing daily feed intake (1.8, 2.3, 2.8, and 3.3 kg/day; 2.50 Mcal of NE/kg and 0.64% SID Lys) from day 90 of gestation until farrowing marginally increased birth weight of piglets born alive (Mallmann et al., 2019). However, increasing daily feed intake in late gestation over 1.8 kg/day resulted in significantly greater stillborn rate (Table H4). This trial also showed a decrease (linear, $P<0.05$) in colostrum yield and lactation voluntary feed intake and an increase (linear, $P<0.05$) in lactation weight loss as feed intake increased.

Table H4. Effects of Increasing Feed Intake in the Last Third of Gestation on Gilt Performance during Lactation Under Commercial Conditions[1]

Item	Feed intake, kg/day				SEM	Probability, P =	
	1.8	2.3	2.8	3.3		Linear	Quadratic
Stillborn rate, %[2]	3.4[a]	4.6[b]	5.5[b]	4.2[b]	0.52	--	--
Colostrum yield, kg[3]	3.6	3.5	3.3	3.2	0.26	0.016	0.703
Voluntary feed intake, kg/d[3]	4.2	4.1	3.8	3.9	0.23	0.001	0.165
Lactation weight change, %[3]	-8.1	-9.3	-11.3	-10.4	0.75	<0.001	0.169

[1]A total of 977 females (Landrace × Large White) were used, with 244, 242, 241, and 250 females for the treatments 1.8, 2.3, 2.8, and 3.3 kg/d, respectively. Table adapted from Mallmann et al., 2019.

[2]Submitted to a nonparametric analysis.

[3]A total of 245 females (Landrace × Large White) were used, with 61, 66, 55, and 63 females for the treatments 1.8, 2.3, 2.8, and 3.3 kg/d, respectively.

[a,b]Different superscripts within a row differ ($P < 0.05$).

These females were followed to their fourth farrowing (Figure H6). Increasing feed intake after day 90 of gestation for gilts numerically reduced retention rate up to their fourth farrowing and reduced the number of days in the herd. Thus, bump feeding gilts may result in increased chances of early culling, which negatively impacts sow longevity (adapted from Mallmann et al., 2019).

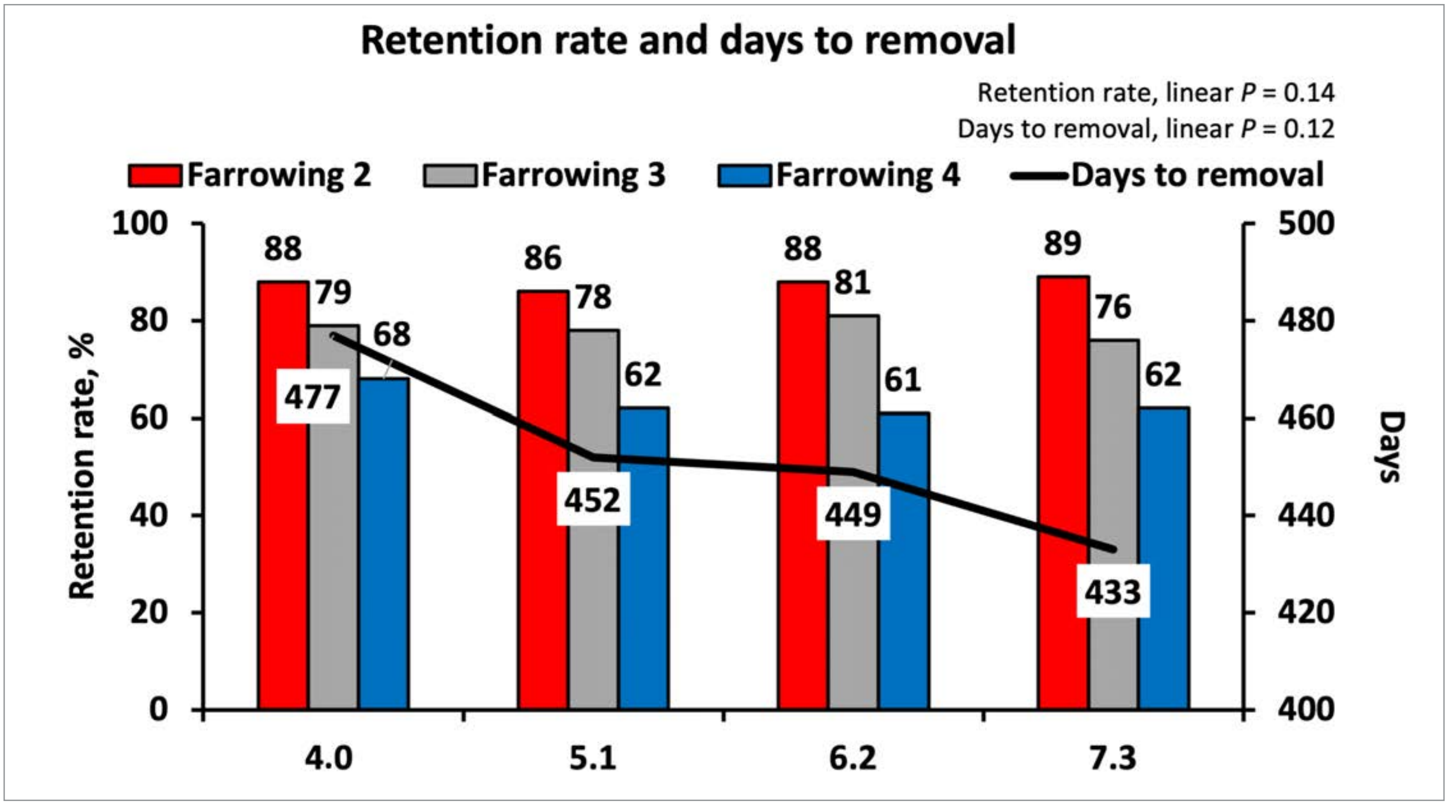


Figure H6. Effects of Increasing Feed Intake in the Last Third of Gestation during the First Parity on Retention Rate in the Subsequent Parities and Days to Removal

Today, PIC® does not recommend bump feeding for gilts or sows, except those with a caliper reading of thin at day 90 of gestation because increasing feed intake in late gestation resulted in a marginal improvement in piglet birth weight. From a practical standpoint, this difference is of little importance compared to the negative effects of bump feeding on stillborn rate, lactation feed intake, and retention in the herd (Gonçalves et al., 2016; Mallmann et al., 2018, 2019). PIC®, universities and production systems worldwide will continue to monitor requirement changes with litter size and litter weight changes.

Peripartum Feeding

- Feed lactation diet at the same level as sows were previously fed in gestation.
- Increase the frequency of feeding during peripartum:
  - May reduce stillbirth rate when farrowing assistance is limited.
  - May improve pre-weaning livability.

Feeding management during the pre-farrowing period (three to five days before farrowing/after moving to farrowing) has been an area of increased interest by researchers (Cools et al., 2014; Decaluwé et al., 2014). Feed allowance historically has been low in this period. Cools et al. (2014) showed that providing *ad libitum* feed prior to farrowing improved weaning weight and piglet growth rate for well-conditioned sows, but negative effects were observed for fat sows. Providing more feed in this period resulted in increased feed intake and decreased mobilization of body reserves during lactation (Cools et al. 2014, Decaluwé et al., 2014). A greater feed allowance during the pre-farrowing period also benefits colostrum yield and nutritional composition (Decaluwé et al., 2014).

Feyera et al. (2018) observed that farrowing duration is reduced if sows have access to feed and eat within 3 hours of farrowing, hypothesizing that this is due to greater energy availability. The authors also observed that the odds ratio of stillbirth is reduced if sows have access to feed within 3 hours prior to the onset of farrowing. Gourley et al. (2020a) have shown that increased SID Lys and energy for 3 or 8 days before farrowing resulted in increased sow and gilts weight gain and born alive piglet birth weight in gilts. However, litter gain from day 2 of age to weaning in gilt litters was reduced when they were fed higher Lys and energy for a longer period (8 days) before farrow. A more recent trial showed no evidence for difference on stillbirth rate of sows fed 1.8 kg/d, 2.7 kg/d, or *ad libitum* since d 112 of gestation until farrowing (Harper et al., 2021). Some veterinarians and nutritionists theorize that especially in herds with too many fat sows and those that induce farrowing, providing *ad libitum* feed before farrowing may increase the risk of uterine and rectal prolapses. Almond et al. (2006) theorized that fat sows might have weakened uterine muscle tone and increased dystocia. This is an additional reason why we caution against *ad libitum* feeding too early or to over-conditioned herds.

Along with increasing feeding levels, increasing feeding frequency during peripartum was reported to improve pre-weaning livability (Gourley et al., 2020b) and reduce stillbirth rate when farrowing assistance is limited (Miller and Kellner, 2020).

Dynamic Feeding Program for PIC® Females

PIC® females are prolific and efficient—underfeeding or overfeeding results in reduced sow and litter performance. Body condition management is key for a successful sow herd. The body condition of the sow is what should guide the feeding program. PIC® recommendations for nutrition and feeding during gestation, peripartum, lactation, and wean to estrus interval are based on research with large-scale, commercial-designed experiments. The Dynamic Feeding Program for PIC® Females tool provides recommendations for feeding modern and highly productive gilts and sows to maximize lifetime productivity and optimize herd profitability. This user-friendly tool uses simple inputs regarding the user's reproductive performance parameters, current feeding programs, and dietary energy and lysine concentration. This tool was developed to help production managers, technical service advisors, and nutritionists:

1. create a tailored feeding program for gilts and sows using the existing diets;
2. evaluate PIC® dietary nutrient recommendations; and
3. compare the opportunities in feed savings per sow per year and reproductive throughput.

Click here to access this application through computers, smartphones, or tablets.

Section I

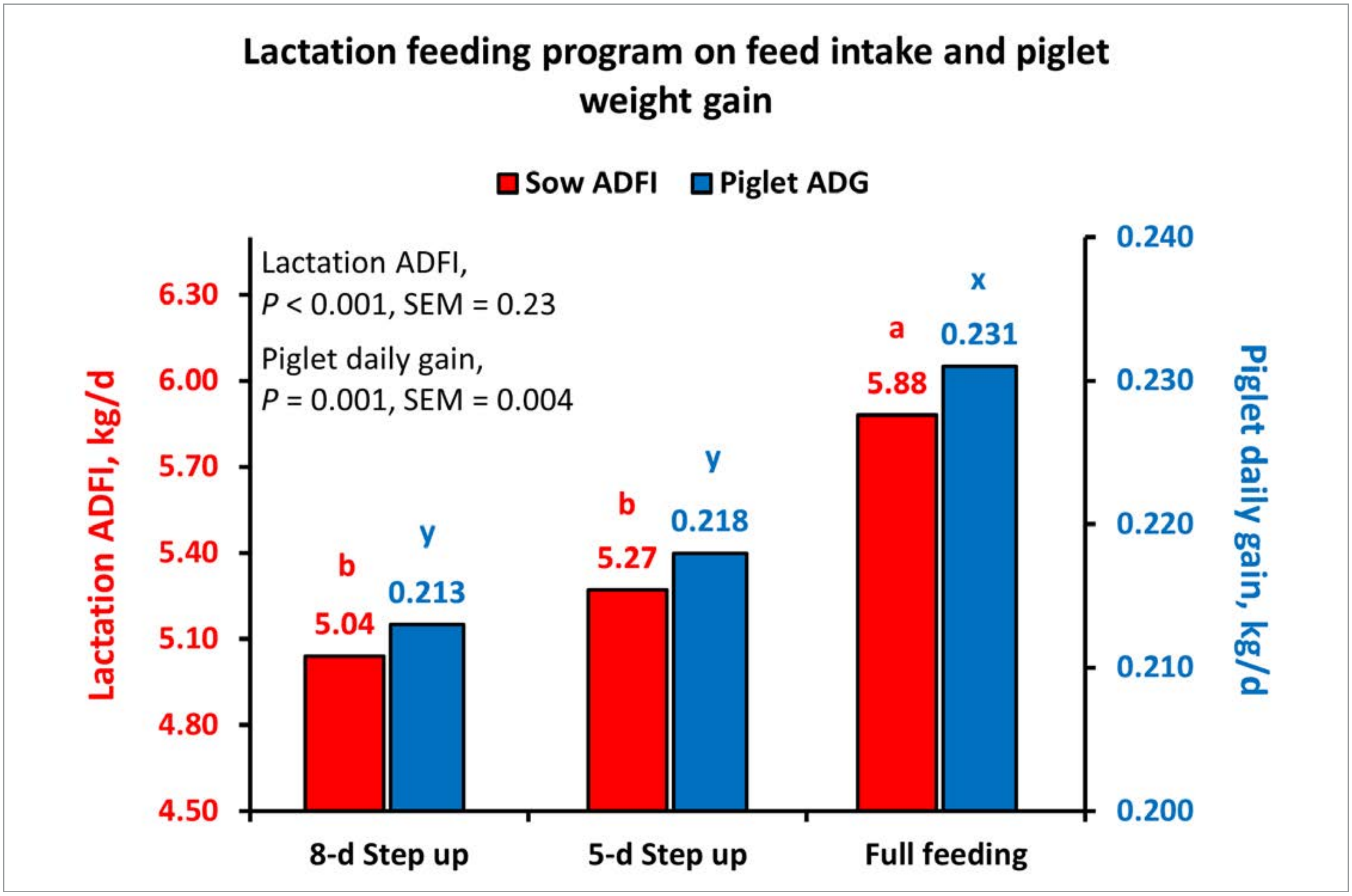
Lactating Gilt and Sow

Lactation nutrition and feeding goals are to ensure sows consume sufficient energy and nutrients daily to optimize litter performance. Adequate nutrient intake should minimize sow weight loss and enhance subsequent reproductive performance.

- Maximizing lactating sow feed intake is critical.
- Having the sows in proper body condition and farrowing her in a comfortable room with access to ample feed and water will go a long way towards maximizing reproductive performance.
- The lactation diet's amino acid concentrations depend on the litter growth rate and herd average feed intake.

Feeding Program

Ad libitum feeding PIC® lactating sows from the day of farrowing improves feed intake, milk yield, and piglet weaning weight (Figure I1) while reducing sow weight loss compared to step-up feeding programs. Restricted feeding for the first 5 to 8 days after farrowing reduces total lactation feed intake (PIC® internal data; Sulabo et al., 2010).



[a,b]Lactation average daily feed intake (ADFI) means without common superscript differ, P < 0.05.

[x,y]Piglet daily gain means without common superscript differ, P < 0.05.

[1]8-d step up: daily feed allowance gradually increased from 1.8 kg on the day of farrowing to *ad libitum* feeding on d 8 post-farrowing; 5-d step up: daily feed
allowance gradually increased from 1.8 kg on the day of farrowing to *ad libitum* feeding on d 5 post-farrowing; Full feeding: *ad libitum* feeding from the day of farrowing until weaning.

Figure I1. Effects of Different Lactation Feeding Strategies on Sow Lactation Feed Intake and Piglet Daily Gain (PIC® internal data)[1]

High lactation feed intake reduces sow body weight loss, increases piglet ADG, and reduces wean-to-estrus interval (Table I1).

Table I1. Effects of Feed Intake during Lactation on Wean-to-Estrus Interval, Body Weight Loss, and Piglet Average Daily Gain (PIC® internal data)

ADFI[1], kg	SID[1] Lys, g/d	Sow BW[1] difference, kg	Sow BW[1] difference, %	Piglet ADG[1], kg	WEI[1], d
3.18	31.5	-26.30	-5.10	0.222	6.3
4.08	42.0	-22.90	-4.81	0.231	5.0
4.99	52.5	-5.80	-1.04	0.249	4.4
5.90	63.0	8.80	2.06	0.249	4.4
6.80	73.5	24.90	5.41	0.249	4.2
8.16	84.0	29.70	6.57	0.259	4.4
9.07	94.5	26.70	5.57	0.272	4.3

[1]ADFI = average daily feed intake; SID = standardized ileal digestible Lys; BW = body weight; ADG = average daily gain; WEI = wean-to-estrus interval.

Factors Influencing Lactation Feed Intake

The factors that can affect lactation feed intake are:

- Environment
  - **Ambient temperature**
  - Air velocity
  - Evaporative cooling
  - Humidity
  - Ventilation rates
- Facilities equipment
  - **Water flow**
  - Feeder design
  - Automated vs. hand feeding
  - Floor surface
  - Crate design
- Gestation feed intake
  - **Body condition at farrowing**
- Sow factors
  - Lactation length
  - Litter size
  - Genetics
  - **Parity**
  - Disease
- Management
  - **Water availability**
  - Feeding frequency
  - Feed allowance
  - Feed freshness
  - Feeder adjustment

Having the sows in proper body condition and farrowing her in a comfortable room with access to ample feed and water will drive towards maximizing reproductive performance.

Amino Acid Requirements

Genetic improvement of PIC® animals has increased litter size and milk production, impacting the lactating female's amino acid requirements. A trial using 1,000 PIC® gilts showed that increasing daily SID Lys intake improved (linear, $P = 0.06$) litter daily gain for gilts, with the greatest improvement observed from 42 to 59 g of daily SID Lys intake (Bruder et al., 2018; Figure I2). Increasing daily SID Lys intake marginally improved (linear, $P = 0.10$) piglet daily gain for lactating gilts and sows, with the greatest improvement observed from 43 to 57 g of daily SID Lys intake (Graham et al., 2018; Figure I9). A recent trial (Silva et al., 2020) using 600 multiparous lactating sows (PIC® Camborough®) found that increasing the SID Lys levels from 0.75 to 1.00% improved litter weight at weaning and piglet daily gain (linear, $P < 0.05$) regardless of dietary energy levels (3.2 or 3.4 Mcal of ME/kg). Based on the available data from the aforementioned trials, PIC® current recommendation is 56.5 g of SID Lys intake per day for sows, 59.0 g of SID Lys intake per day for gilts (minimum 50 g of SID Lys intake per day if using single lactation diet), and 57.0 g of SID Lys intake per day on herd basis.

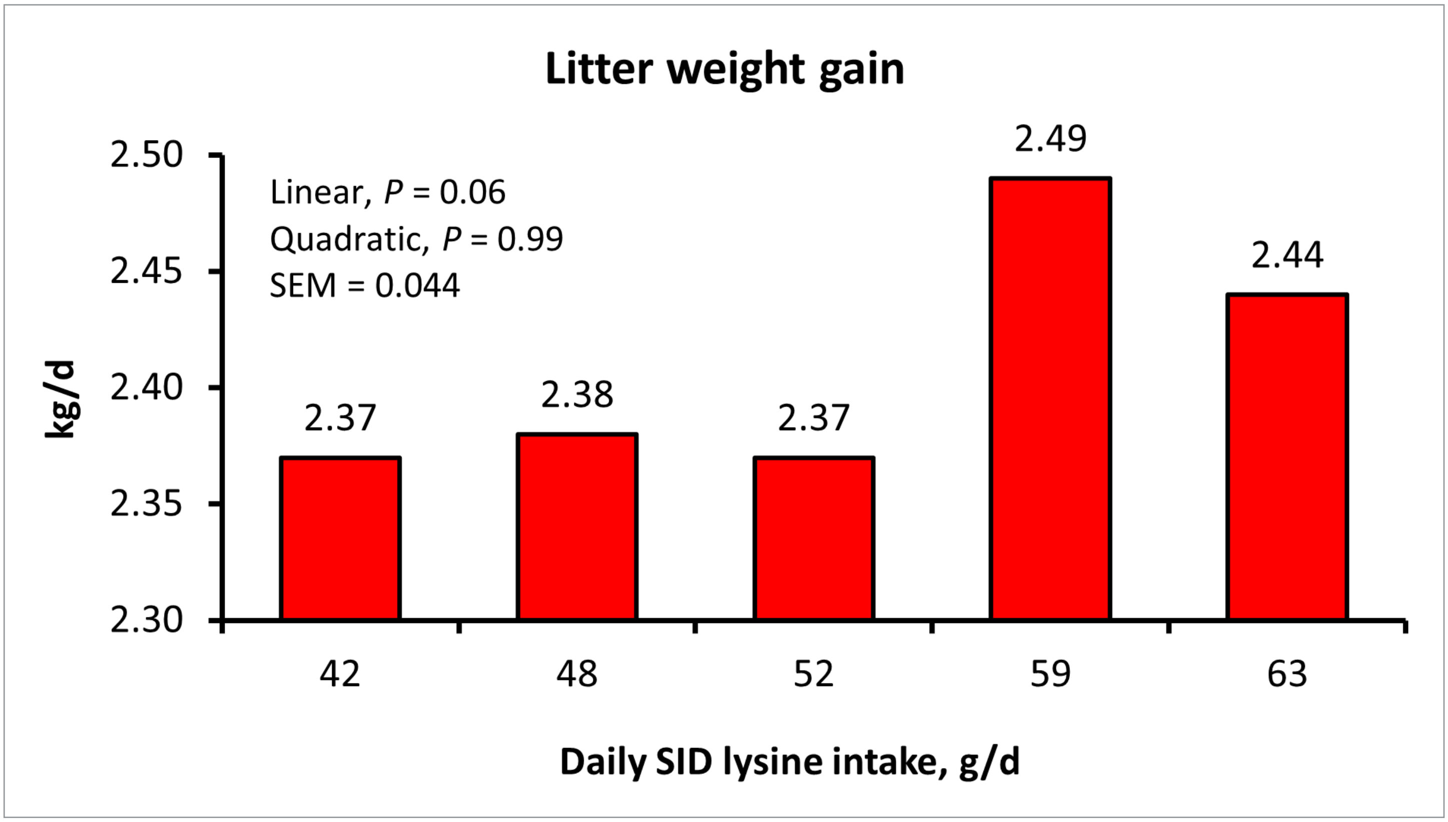


Figure I2. Effects of Daily SID Lys Intake on Litter Weight Gain of Lactating Gilts (Bruder et al., 2018)

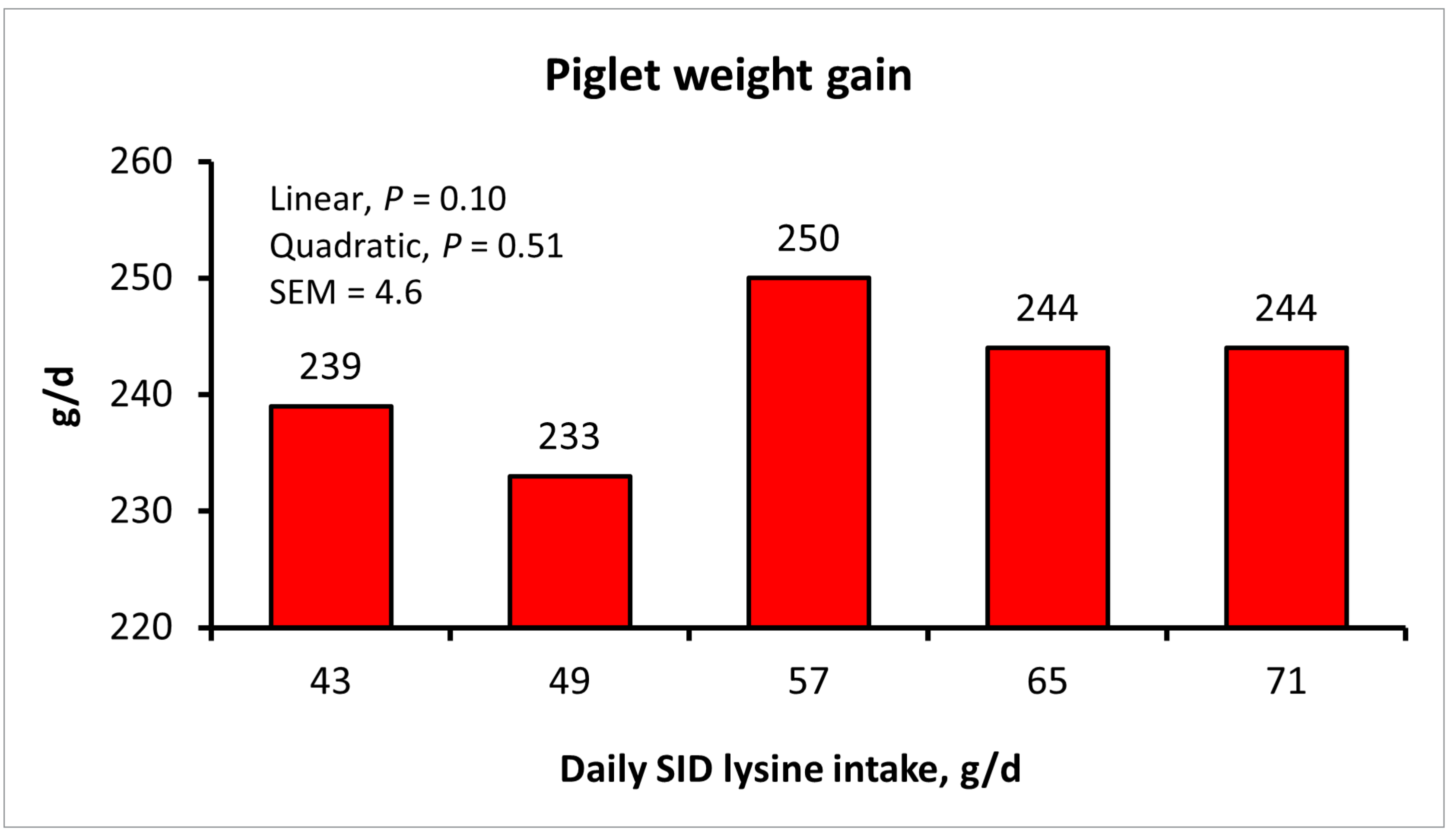


Figure I3. Effects of Daily SID Lys Intake on Piglet Weight Gain of Lactating Gilts and Sows (Graham et al., 2018)

The dietary Lys level during lactation depends on litter growth rate and herd average feed intake. Table I2 illustrates how litter growth rate and sow feed intake are used to derive farm-specific dietary SID Lys levels. PIC® recommends setting a maximal SID Lys level of 1.30% for lactation diet from a practical standpoint. Lactation diets that contain greater than 30% soybean meal reduce ADFI (Gourley et al., 2020c).

Table I2. Dietary Lys Concentrations (%) Based on Litter Growth Rate and Lactating Sow Feed Intake[a]

Litter growth rate, kg/d	Average feed intake, kg/d					SID Lys, g/d
	4.5	5.0	5.4	5.9	6.4	
2.0	0.96	0.87	0.80	0.74	0.68	43.3
2.3	1.09	0.99	0.91	0.84	0.78	49.6
2.5	1.23	1.12	1.03	0.95	0.88	55.9
2.7	1.37[b]	1.25	1.14	1.05	0.98	62.1

[a]Adapted from Tokach et al., (2019). The relationship between litter growth rate and Lys needs (g/d) was established based on the published studies conducted between 1998 and 2017 with primiparous and multiparous sows (Sauber et al., 1998; Yang et al., 2000, Xue et al., 2012; Gourley et al., 2017), assuming 21 days of lactation and the Lys need is not strictly related to energy intake.

[b]PIC® does not recommend lactation diets containing more than 300 kg per ton of soybean meal or SID Lys levels over 1.30%.

Threonine and valine are considered the second and third limiting amino acids for lactation (Kim et al., 2001). Greiner et al. (2017) reported increasing dietary SID threonine to Lys ratios (52, 60, 68, 76, and 84%; n=291, PIC® Camborough®) improved daily litter gain (quadratic, $P = 0.001$; Figure I4). The broken-line quadratic model determined the optimal SID threonine to Lys ratio for litter growth at 65%. The optimal SID valine to Lys ratio was evaluated using 990 PIC® Camborough® sows (Touchette et al., 2018). Increasing SID valine to Lys ratio from 58 to 93% quadratically improved piglet weaning weight ($P = 0.06$; Figure I5). It was concluded that dietary SID valine to Lys ratio as low as 65% could be fed without affecting sow or piglet performance.

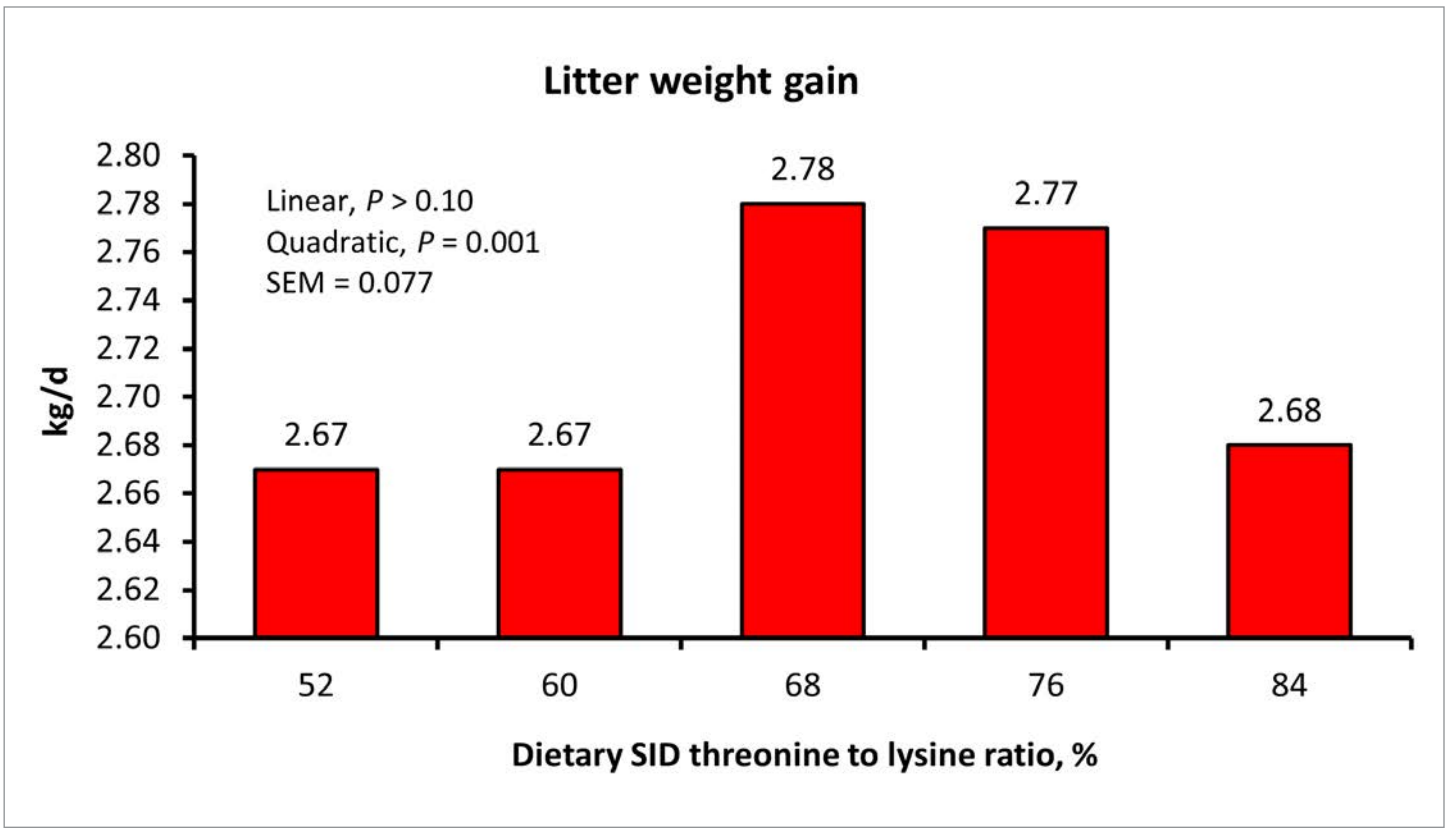


Figure I4. Effects of Dietary SID Threonine to Lys Ratios on Litter Weight Gain of Lactating Sows (Greiner et al., 2017)

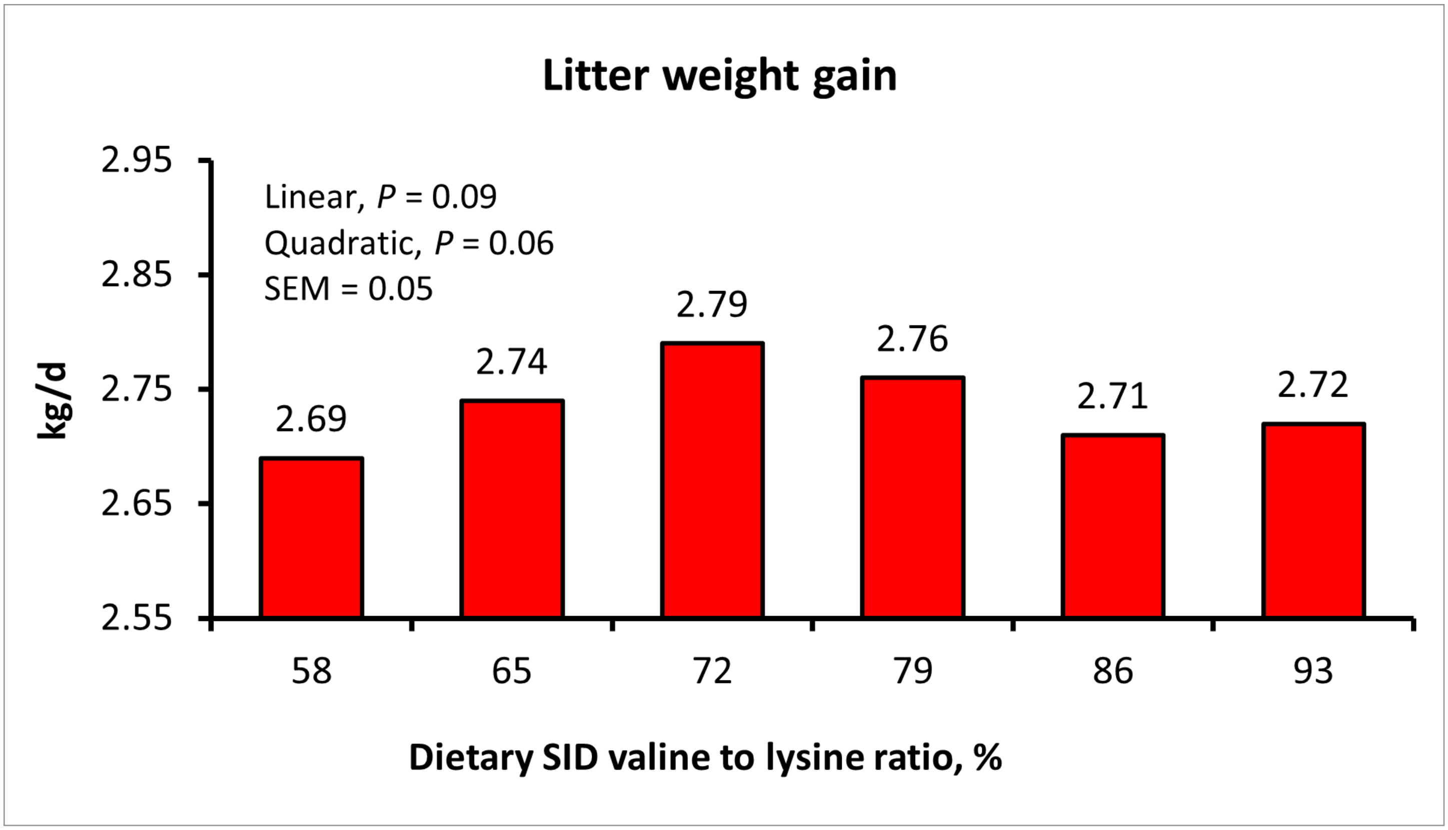
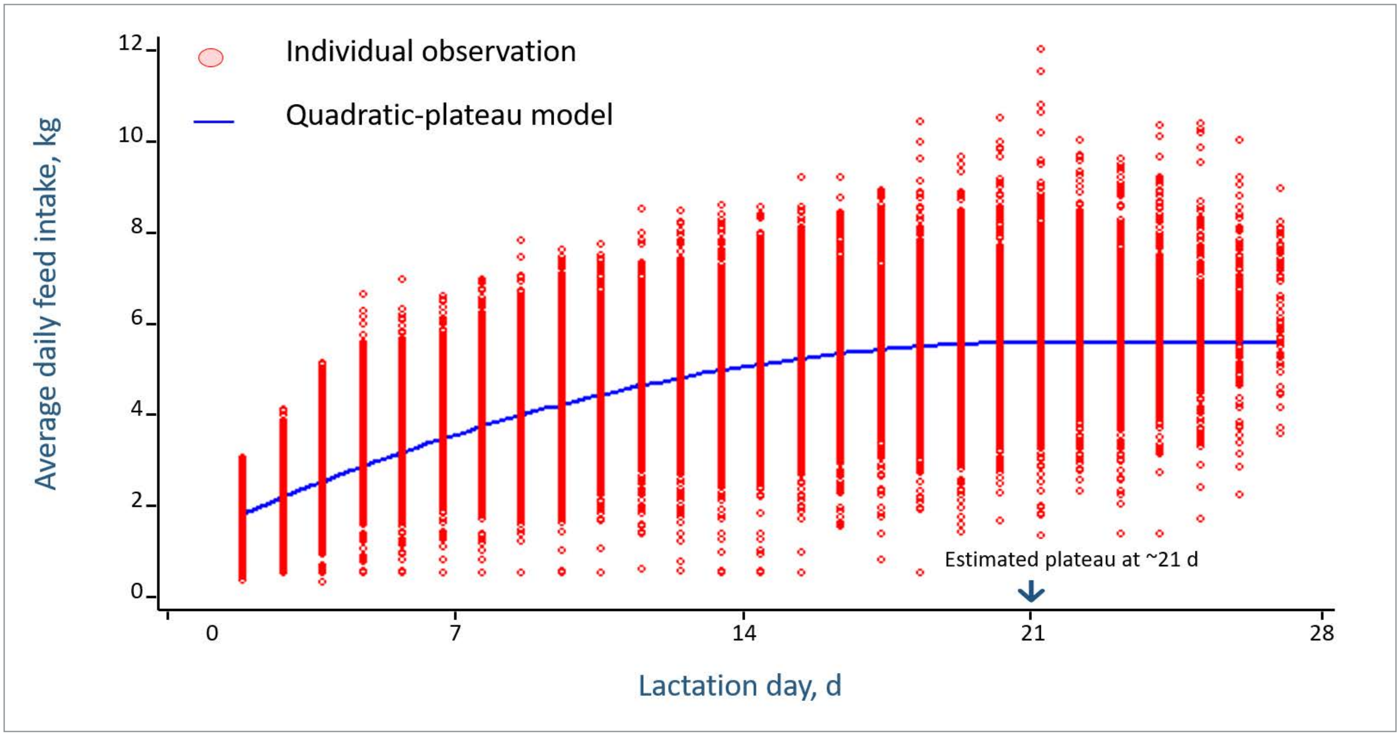


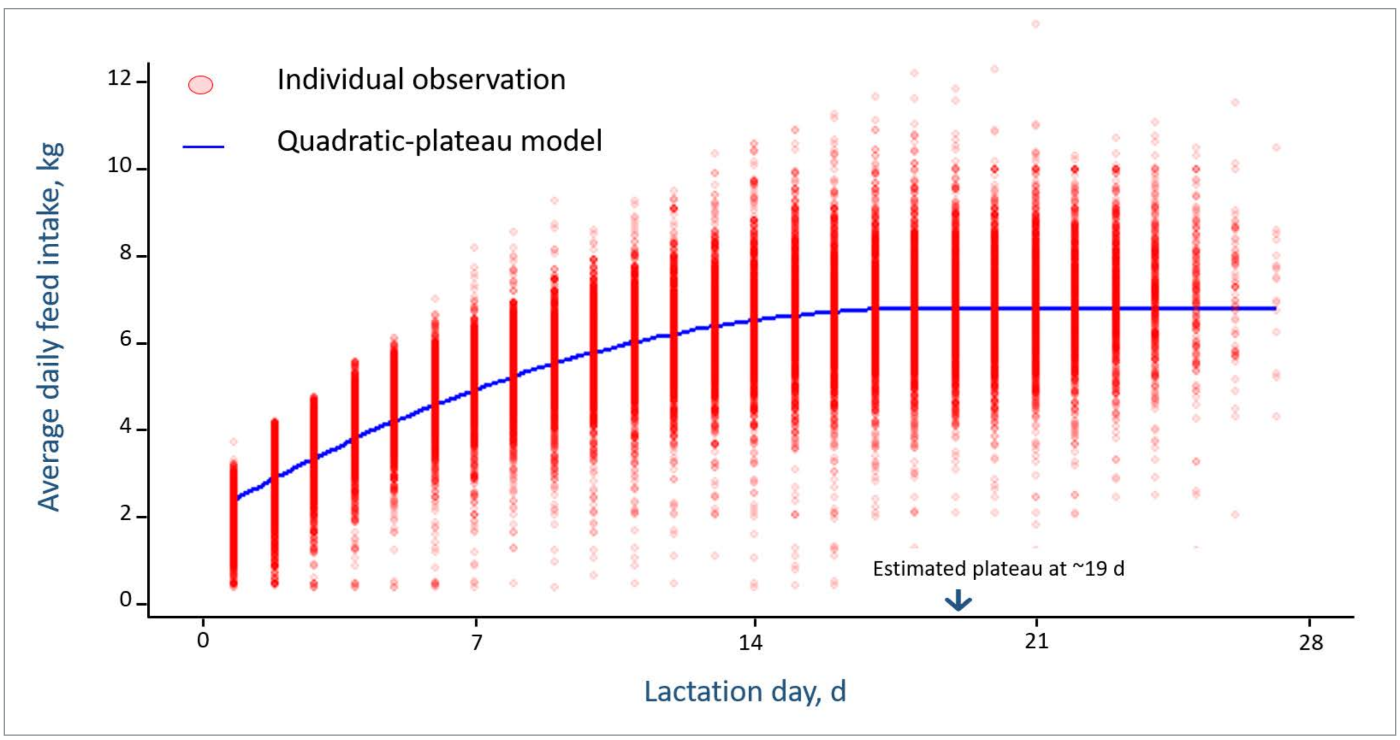
Figure I5. Effects of Dietary SID Valine to Lys Ratios on Litter Weight Gain of Lactating Sows (Touchette et al., 2018)

A total of 37,402 feed intake observations collected from 405 PIC® Camborough® and 1,665 PIC® L03 sows in two commercial sow farms over a 10-month and 3-year period, respectively, were evaluated to quantify and model lactation daily feed intake for parity 1 and parity 2+ sows (Figure I6 and I7). The gilt lactation feed intake model shows that the feed intake reaches a plateau at around 21 days of lactation, and the overall lactation ADFI increases by ~47 g for each day above 21 days. The parity 2+ sows lactation feed intake model shows that the feed intake reaches plateau at around 19 days of lactation, and the overall lactation ADFI increases by ~57 g for each day above 19 days.



[a]Daily feed intake is estimated as a function of day of lactation. Daily feed intake for parity 1 sows = (3.234049 + 0.949148 × Day - 0.022863 × Day^2) ÷ 2.204622 (kg/d, R^2 = 0.53)

Figure I6. Daily Feed Intake during Lactation for PIC® Parity 1 Sows (Jerez et al., 2021)[a]



[a]Daily feed intake is estimated as a function of day of lactation. Daily feed intake for parity 2+ sows = (4.104837 + 1.201068 × Day - 0.031364 × Day^2) ÷ 2.204622 (kg/d, R^2 = 0.60)

Figure I7. Daily Feed Intake during Lactation for PIC® Parity 2+ Sows (Jerez et al., 2021)[a]

Ensure fresh feed and correctly adjust lactation feeders to stimulate feed intake (Figures I8 and I9).

Figure I8. Correctly Adjusted Lactation Feeder with Fresh Feed

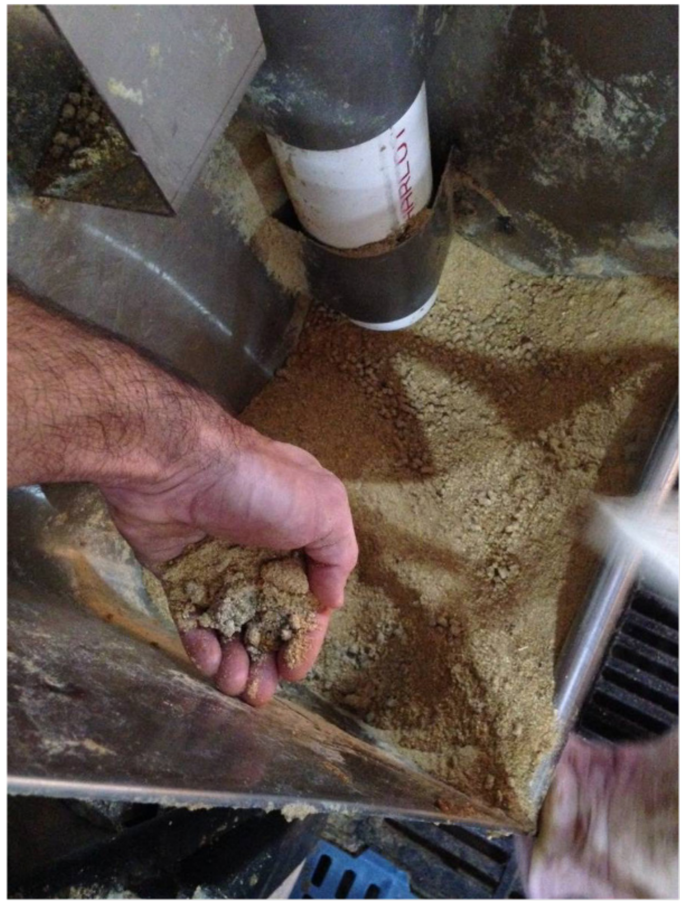


Figure I9. Incorrectly Adjusted Lactation Feeder with Moldy Feed

Dynamic Feeding Program for PIC® Females

Adequate nutrient intake during lactation is one of the most critical points to realize the genetic potential of PIC® females. The interactive web-based application, Dynamic Feeding Program for PIC® females, evaluates users' dietary and production information and provides customized recommendations to help the lactating sows meet daily nutrient intake requirements. Click here to access this application through computers, smartphones, or tablets.

Section J

Weaned Sow

Feeding management of the weaned sow focuses on starting the recovery of body reserves lost during lactation and supporting ovulation rate to ensure a large subsequent litter size.

- Nutrition and feeding during the wean-to-estrus interval cannot fix prior issues such as over condition in gestation and poor lactation intake.
- Feeding 2.7 kg/d of gestation diet to provide 8.7 Mcal of ME and 16.0 g of SID Lys per day is enough to maximize subsequent reproductive performance.
- Only provide feed *ad libitum* for sows with caliper reading of thin.
- Do not skip a meal (think about the practical implications on wean day).
- Group sows by body condition.
- Ensure feed is fresh to minimize waste and spoilage.

Feed Program during the Wean-to-Estrus Interval

Menegat et al. (2018) have demonstrated that 2.5 kg/d of a gestation diet containing 3,230 kcal ME/kg and 0.60% SID Lys seems to be enough to meet the SID Lys and energy requirements of the weaned sow (Figure J1). The body condition of the weaned sow should define feeding levels.

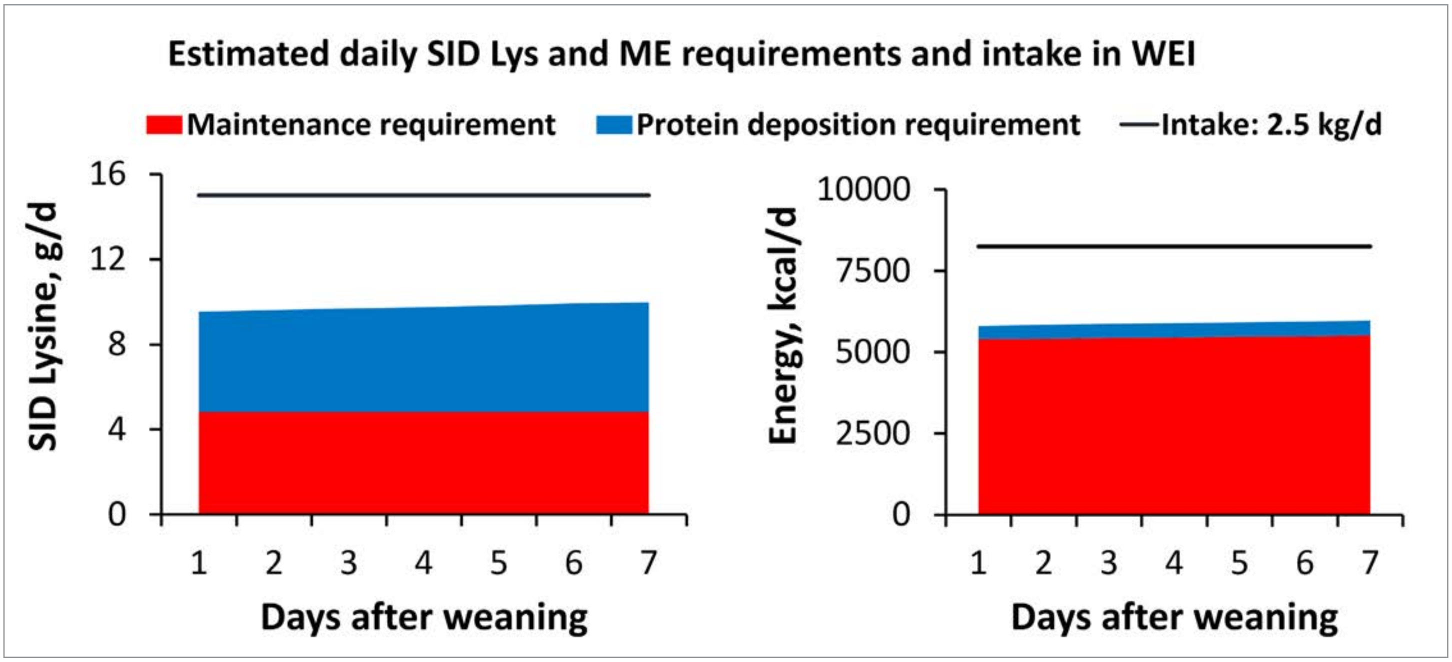


Figure J1. Estimated Daily SID Lys (g/d) and ME (kcal/d) Requirements and Intake of Multiparous Sows During Wean-to-Estrus Interval (Adapted from Menegat et al., 2018). It Assumes 1.0 kg/d gain and Feeding Level of 2.5 kg/d from d 1 to 7 After Weaning of a Gestation Diet Containing 3,230 kcal ME/kg and 0.60% SID Lys

Several recent large-scale commercial experiments demonstrated that sows in good body condition do not benefit from high feed allowance during the wean-to-estrus interval (WEI; Table J1). Graham et al. (2015) reported no evidence for differences in WEI, farrowing rate (FR), total born (TB) and born alive (BA) when sows with a body condition score > 2.75 were fed 2.7, 3.6, or 5.5 kg/d. Almeida et al. (2017) observed improvements in FR and number of piglets BA for every 100 sows bred (BA index) when sows were offered 3.7 kg/d compared to 2.7 kg/d. However, three subsequent studies failed to demonstrate any reproductive performance improvements with increasing feed over 2.7 kg/d during the WEI (Almeida et al., 2018; Gianluppi et al., 2019; Lu et al., 2021). Increasing feed intake during the WEI has been shown to improve under-conditioned sows' reproductive performance (Baidoo et al., 1992).

Table J1. Summary of Experiments on the Effects of Feeding Levels during the Wean-to-Estrus Interval on Sow and Piglet Performance

Experiment	Feed Allowance, kg/day	Wean to Estrus Interval, days	Farrowing Rate, %	Total Born, n	Born Alive (BA), n	BA index[1], n
Graham et al., 2015	2.7	5.1	85.4	14.3	13.1	1,119
	3.6	5.0	87.0	13.9	12.9	1,122
	5.5	5.0	82.3	13.9	12.9	1,062
Almeida et al., 2017	2.7	NR	88.3[b]	14.6	13.4	1,144[b]
	3.7	NR	93.3[a]	15.0	13.7	1,262[a]
Almeida et al., 2018	2.6	4.2	88.1	15.1	13.8	1,219
	3.5	4.2	88.2	15.3	13.8	1,220
Gianluppi et al., 2019 – P1	2.7	5.0	92.0	14.0	13.3	1,227
	4.3	5.7	86.1	13.8	13.2	1,135
Gianluppi et al., 2019 – P2+	2.7	4.5	93.4	15.2	14.3	1,340
	4.3	4.6	92.6	15.5	14.5	1,340
Lu et al., 2021[2]	3.0	4.7	97.4	15.3	14.0	1,372
	4.5	4.7	95.7	15.6	14.3	1,362

[a,b]Means with different superscripts within column and experiment differ, $P < 0.05$.

[1]Number of piglets born alive for every 100 sows bred calculated as BA index = farrowing rate, % × piglet born alive, n × 100.

[2]The sows in control group were fed 3 kg of gestation diet/d; and sows in treatment group were fed 4.5 kg of gestation diet/d and 200 gr of glucose/day.

Recent trials show no benefit in feeding a lactation diet during the WEI (Figure J2. Almeida et al., 2018; Gianluppi et al., 2019).

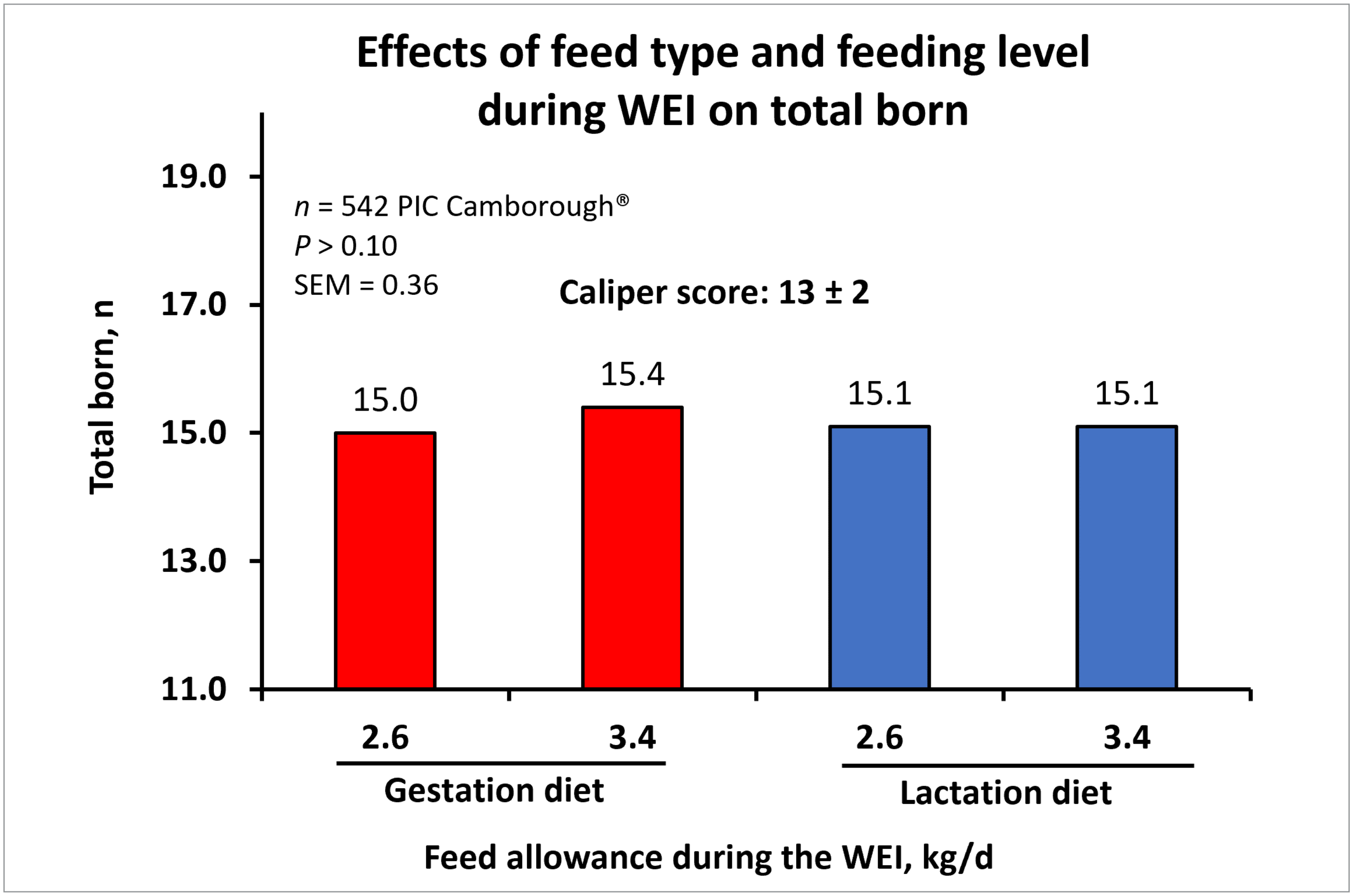


Figure J2. Total Born Piglets from Sows in Good Body Condition Fed a Gestation or Lactation Diet during the Wean-to-Estrus Interval (Almeida et al., 2018)

PIC® recommends feeding 2.7 kg (8.7 Mcal ME/d) per day of a conventional gestation diet to sows with a caliper reading of ideal. Only provide *ad libitum* feed to sows with caliper reading of thin. Avoid skipping meal on weaning day since it negatively impacts lutenizing hormone secretion compromising sow fertility. It is advisable to group sows in the weaner row based on their body condition. Weaned sow feeding management requires a balance between providing enough fresh feed and avoiding waste and spoilage. Split the daily feed allowance of the weaned sow into 2 to 3 meals.

Section K

Nursery Pig

The nursery nutrition program focuses on maximizing feed intake in the first week after weaning, preferably utilizing highly digestible diets. The goal is to transition pigs to simpler diets as quickly as possible.

- Age at weaning and high feed intake after weaning are critical to maximize performance in the nursery phase.
- Do not feed dairy products and specialty protein sources past 42 days of age.
- Meet the Lys requirement in the last phase of the nursery since this represents the greatest portion of nursery growth.
- Adequate amino acid ratios are especially critical in diets formulated at or below the SID Lys requirement.
- The sodium requirements of nursery pigs as recommended by NRC 2012 are sound. Often in today's diets, more salt needs to be added to reach NRC levels because alternative lactose sources and less animal proteins are used.

Weaned Pig

Weaning age is an important factor because it directly impacts weaning weight, post-weaning growth performance, and livability. Studies on weaning age have shown the benefits of increasing age to improve subsequent growth performance, survival, intestinal barrier function, and immunological response (Main et al., 2004; Moeser et al., 2007). An older weaned pig is physiologically more mature and better able to transition to dry feed. Due to the pressure to reduce antibiotic use in the swine industry, the importance of weaning age will continue to increase.

Recently, Faccin et al. (2020) evaluated the effects of increasing weaning age (18.5, 21.5, 24.5 d) and feed antibiotic use on pig performance in a commercial production system. The authors did not observe any interactions between the two factors, and both contributed to improve performance and weight sold per pig weaned. Each day increase in weaning age resulted in an additional 0.70 kg per pig sold.

Maximizing feed intake of weaned pigs is essential as they are extremely dependent on energy intake. Increasing feed intake during the first week after weaning increases digesta flow, decreases proliferation of bacteria in the gut, and reduces diarrhea incidence.

It is crucial to provide *ad libitum* access to feed and water immediately upon arrival. A large epidemiological study indicated that low feed intake after weaning increases the likelihood of developing diarrhea compared to high feed intake (Madec et al., 1998). Therefore, age at weaning and high feed intake after weaning are critical to maximize performance in the nursery phase. For information on management aspects that improve feed intake after weaning, such as mat and gruel feeding, please click here to access the PIC® Wean to Finish Manual.

Phase Feeding

Based on the development of weaned piglets' digestive system, three diets are typically fed during the nursery period. The feeding duration of each phase will vary according to weaning age (Table K1). In general, PIC® recommends feeding phases 1 and 2 to pigs no longer than 42 d of age. This is due to the high costs of dairy products and specialty proteins in early nursery diets. The nursery feeding program corresponds to approximately 10 to 15% of the total feed cost to produce a pig.

Table K1. Feeding Duration Recommendations for Nursery Diets According to Weaning Age[1]

Weaning age, days	Phase 1 Weaning to ~7.5 kg		Phase 2 ~7.5 to 11.5 kg		Phase 3 11.5 to 22.5 kg	
	Duration, d	Exit age, day	Duration, d	Exit age, day	Duration, d	Exit age, day
18 to 20	8	26 to 28	14 to 16	42	21	63
21 to 22	7	28 to 29	13 to 14	42	21	63
23 to 24	6	29 to 30	12 to 13	42	21	63
25 to 28	5	30 to 33	9 to 12	42	21	63

[1]Feed budget will depend on feed intake, which may vary according to management, delivery logistics, feeder design, health status, etc.

Phase 1 – Weaning to ~7.5 kg

Feeding newly weaned pigs requires a diet with greater inclusions of highly digestible carbohydrates and protein sources to maximize feed intake while matching their digestive capabilities. This diet typically has a greater cost per ton than subsequent phases.

The most commonly used highly digestible carbohydrates are sources of lactose, such as crystalline lactose, dried whey, and whey permeate. High lactose levels of 14% or greater are desired but need to be used for a short time due to the high cost. Dried whey is typically preferred over whey permeate because of more consistent quality; however, high-quality whey permeate can be the sole source of lactose. Other highly digestible carbohydrates sources can replace part of the lactose if economical and quality is assured (i.e., maltose, dextrose, maltodextrin, micronized corn, micronized rice, oat groats, etc; Guo et al., 2015). Care must be taken with the source of lactose and, generally, edible-grade lactose sources are the preferred option (Bergstrom et al., 2007).

Weaned pigs have a transitory hypersensitivity to soybean meal (Engle, 1994). A practical maximum is 20% of SBM in this phase to help adapt to simpler diets with greater SBM inclusion in the subsequent phases. Plant protein sources typically provide most of the protein in nursery diets, but feed grade amino acids and animal protein sources can reduce soybean meal inclusion in early nursery diets. Soy protein concentrate can be used up to 14% and fermented soybean meal can be included from 6 to 15% without adversely affecting growth and intake (Cho et al., 2007; Jones et al., 2010; Kim et al., 2010). One study, however, indicated marginally lower overall nursery feed intake feeding fermented soybean meal at an 8% inclusion rate. Fish meal can be included at approximately 3 to 6% to stimulate feed intake in early nursery diets (Jones et al., 2018). Be aware fish meal quality can vary significantly among sources (Kim and Easter, 2001), with mineral and fat content being an indicator of fish meal feeding value (e.g., maximum 20% ash and minimum 7.5% fat).

Phase 2 – ~7.5 to 11.5 kg

Reduce diet complexity in phase 2, with diets comprised of a grain source, soybean meal, and lower levels of lactose and specialty protein sources. Lactose is typically decreased to approximately 7%, while SBM level are usually increased to a maximum of 28% of the diet (Jang et al., 2019). With the wide scale availability and lower cost of feed grade tryptophan, valine and isoleucine specialty proteins can be economically reduced or eliminated in this diet.

Phase 3 – 11.5 to 22.5 kg

The phase 3 diet is primarily comprised of a grain source and soybean meal with no inclusion of lactose or specialty protein sources. It contains similar ingredients to grow-finish pig diets. Nursery growth potential is the greatest during this phase and it is crucial to meet their nutrient needs, especially Lys.

Other Considerations

Sometimes it's thought that extra gain in the nursery period multiplies itself in the finisher period. The extra gain achieved in the nursery from nutritional interventions may be maintained throughout grow-finish but does not likely increase. Several studies have shown that the use of complex diets increases feed intake and growth rate in young pigs (Wolter et al., 2003; Skinner et al., 2014; Lunedo et al., 2020). However, the benefit gained in the nursery did not increase through the finisher (Whang et al, 2000; Wolter et al., 2003; Skinner et al., 2014).

Increasing the dietary Lys and other AA in nursery diets have resulted in improved growth rate and feed efficiency (Kendall et al., 2008; Jones et al., 2014). However, recent research has demonstrated that nursery pigs can also experience compensatory growth after a short period of AA deficiency (Nemecheck et al., 2018; Totafurno et al., 2019). Practical implications are that dietary Lys can be reduced during the first two to three weeks post-weaning, lowering feed costs and crude protein content of the diet, which could positively impact gut health (Heo et al., 2009).

Research has shown that the inclusion of feed-grade AA can be used as a partial replacement of specialty proteins as long as the SID Lys to crude protein ratio is kept below 6.40 (Millet et al., 2018). The use of adequate amino acid ratios is especially critical in diets formulated at or below the SID Lys requirement (Clark et al., 2017a).

Dietary tryptophan to Lys ratio has a significant impact on feed intake and growth rate. Depending on a system's specific scenario of fixed time or fixed weight, varying tryptophan to Lys ratio could greatly impact profitability. Refer to Section A for detailed information of the optimum SID tryptophan to Lys ratio tool. Besides protein synthesis, threonine is also involved in gut health and immunity (Ruth and Field, 2013). Dirty environment and health challenges may influence the threonine requirement. PIC® has updated the dietary threonine to Lys ratio for nursery pigs based on a recent study conducted under commercial conditions (De Jong et al., 2018). Also, several other dose-response studies have determined the amino acid requirements of nursery pigs (Gonçalves et al., 2015; Jayaraman et al., 2015; Clark et al., 2017b; Kahindi et al., 2017; Cemin et al., 2018) and can be used as a reference to set the recommendations for AA ratios. For more details on amino acids, refer to Chapters A and C.

The sodium (Na) requirements of nursery pigs from 5.5 to 6.8, 6.8 to 11.5, and 11.5 to 22.5 kg are 0.40, 0.35, and 0.28%, respectively (NRC, 2012; Shawk et al., 2018). Often in today's diets, more salt must be added to meet the pig Na needs because of less use of fish and animal proteins. The lactose source seldom will supply all the Na required. It is also important to minimize excess calcium in diets for young pigs to avoid a reduction in performance, especially when phosphorus levels are at or below the requirements (González-Vega et al., 2016a,b; Merriman et al., 2017, Wu et al., 2018). For more details on calcium and phosphorus requirements, refer to Section D.

Section L

Grow-Finish Pig

The goal for grow-finish diets is to maximize return on investment.

- PIC® Lys and phosphorus biological recommendations are updated based on recent research.
- New tools to determine the most cost-effective energy, Lys, tryptophan, and phosphorus levels are available, click here to access those tools.
- Recent trials have shown that excess leucine may require adjustments to isoleucine, valine, and tryptophan ratios.
- Proactively act on strategies to increase market weight for anticipated times of high profitability with the PIC® Seasonal Diet Formulation tool.

Formulating Grow-Finish Diets

The steps in diet formulation for finishing pigs comply with the principles described in Section A of this manual, which are:

1. **Determine the Optimal Lys:Calorie Ratio**
   The biological SID Lys Requirement tool helps users determine the SID Lys level that maximizes the growth rate of pigs within a given body weight range. An update of the PIC® SID Lys Biological tool allows it to be applicable from 11 to 150 kg. The SID Lys Economic Calculator helps users to compare the economics of their existing Lys levels with the biological Lys requirements. Refer to Section C for detailed information on the biological SID Lys Requirement tool and the SID Lys Economic Calculator.

2. **Determine the Most Economical Energy Level**
   Energy is the major cost of any grow-finish diet and does affect growth performance significantly. The optimum NE tool helps users determine the dietary NE content that yields the greatest income over total cost on a live or carcass basis. Refer to Section B for detailed information on the optimum net energy tool.

3. **Determine the Ratio for the Other Amino Acids**
   Dietary tryptophan to Lys ratio has a significant impact on feed intake and growth rate. Depending on a system's specific scenario of fixed time or fixed weight, varying tryptophan to Lys ratio could greatly impact profitability. Refer to Section A for detailed information on the optimum SID tryptophan to Lys ratio tool.

   Using the fibrous by-products from corn or wheat processing in grow-finish diets is a common practice to reduce feed cost. However, greater dietary fiber levels may influence the optimal levels of threonine. Mathai et al. (2016) reported the threonine to Lys ratio for maximizing ADG increased from 66 to 71% when dietary NDF levels increased from 8.3 to 16.6% in 25 to 50 kg pigs.

   Valine is commonly considered to be the fifth limiting amino acid in corn-soybean meal-based diets for finishing pigs (Figueroa et al., 2003). A recent study reported that 68% and 63% of SID Val:Lys ratio achieved 99% of the maximum mean ADG and G:F for 25 to 45 kg pigs (Gonçalves et al., 2018).

   Increasing the dietary SID leucine to Lys ratio from 100 to 300% linearly reduced growth rate, feed intake, and worsened feed efficiency (Kwon and Stein, 2019; Kwon et al., 2019). Leucine is usually in excess in corn-based diets due to its high concentrations in corn or corn by-products. A meta-analysis with 44 trials concluded that the addition of valine, isoleucine, and tryptophan, alone or in combination, has the potential to mitigate the adverse effects of excess leucine on growth performance (Cemin et al., 2019). Increasing dietary SID tryptophan to Lys ratio alone only partially alleviated the negative impact of excessive dietary leucine. Example of adjustments in branched chain amino acid ratios according to leucine levels is shown in Section R.

   The suggested ratios of dietary amino acid to Lys are in the nutrient specification tables at the end of this manual.

4. **Determine the Phosphorus Level**
   Phosphorus is the third most expensive nutrient in swine diets. Phosphorus is required for growth, lean tissue deposition, and bone mineralization (Berndt and Kumar, 2009). The optimum STTD P tool determines the biological requirement and helps users to compare the economics of their existing STTD P levels with the biological requirement. Refer to Section D for detailed information of the optimum STTD phosphorus tool.

5. **Set Levels of Calcium, Vitamins, Trace Minerals, Salt, and Other Ingredients.**
   The ratio between calcium and phosphorus generally determines dietary calcium level. Vier et al. (2019b) reported the analyzed Ca to analyzed P ratio that maximized ADG for 26 to 127 kg pigs was 1.63:1 and 1.38:1 when diets were with or without 1000 FYT/kg phytase, respectively.

   Adding vitamins in diets at levels excess to NRC (2012) requirement estimates is a common industry practice. Recent studies have refined vitamin levels needed for performance (Tuffo et al., 2019; Thompson et al., 2020). Vitamin requirements in the nutrient specifications table in this manual are based on the results of these trials.

   In addition to the above five steps of formulating grow-finish diets, adjusting diet formulations based on seasonal variation of performance and market pricing could help maximize profitability. Refer to Section A for detailed information on the PIC® Seasonal Diet Formulation tool.

Phase Feeding

Phase feeding represents a strategy commonly used across the swine industry to closely meet the nutrient requirements of grow-finish pigs within a given weight range. There has been an interest in simplifying phase feeding programs due to the benefits in diet manufacturing, delivery, and storage logistics. Simplification could result in improved feed mill efficiency (Moore et al., 2013).

Menegat et al. (2020a) reported that a single-phase feeding program compromised grow-finish pigs' performance compared to multi-phase feeding programs (4, 3, or 2 phases). However, overall growth performance, carcass characteristics, and income over feed cost (IOFC) were maintained when reducing dietary phases from four to three to two when providing 100% of the PIC® recommended SID Lys levels.

Performance could be compromised if the initial body weight and feed intake are lower than expected. Other considerations would be the degree of SID Lys restriction, the duration of the restriction, the ratio between the time of restriction and time of recovery, and the SID Lys adequacy in the recovery diets (Menegat et al., 2020b). The financial implications under varying production and economic situations should dictate the implementation of fewer phases.

A feed budget is used to properly match the pig's requirement by delivering the right feed at the right time, independent of number of dietary phases. Thus, a feed budget is an important tool to minimize the chances of under- or over-feeding nutrients. To help determine the correct amount of each feed per pig according to dietary energy levels and phases, target market weight, and customer specific performance access the PIC® Feed Budget tool (click here).

PIC® Adjusted Caloric Efficiency Calculator

Multiple factors influence the feed efficiency of wean to finish pigs. Four major factors affecting feed efficiency are: dietary energy level, genetics, entry and final body weight, and mortality.

Dietary energy may change through time because of the varying ingredient pricing. A one percentage change of dietary energy level is expected to change feed efficiency by 1% (Euken, 2012). Adjusting for dietary energy level is important in comparing close-out performance. Offspring from different genetics (sirelines) have different growth rate and feed efficiency. Using sireline-specific coefficients to adjust for entry and final weights helps in improving the accuracy. Adjusting feed efficiency for final weight in the nursery phase and entry and final weight in the finishing phase is common to account for differences in feed efficiency due to differences in body weight. If assuming mortality occurs at the mid-point of the finishing phase, feed efficiency becomes poorer by 0.5 to 0.8% for every 1% increase in mortality (Tokach et al., 2014). Click here to access the PIC® Adjusted Caloric Efficiency calculator. Refer to the KSU Feed Efficiency Calculator to consider other factors that can impact feed efficiency, such as diet form, seasonality, temperature, and ractopamine use (if allowed).

PIC® Nutrient Specifications for Mature Boars (As-Fed)

ITEM[a]	UNIT	
Standardized ileal digestible amino acids		
Lys:Calorie NE	g/Mcal	2.64
Lys:Calorie ME	g/Mcal	1.95
Methionine + Cysteine:Lys	Ratio	70
Threonine:Lys	Ratio	74
Tryptophan:Lys	Ratio	20
Valine:Lys	Ratio	67
Isoleucine:Lys	Ratio	58
Leucine:Lys	Ratio	65
Histidine:Lys	Ratio	30
Phenylalanine + Tyrosine:Lys	Ratio	114
L-Lys-HCl, max.[b]	%	0.25
Minerals		
STTD P:Calorie NE[c]	g/Mcal	1.87
STTD P:Calorie ME[c]	g/Mcal	1.38
Av. P:Calorie NE[c,d]	g/Mcal	1.78
Av. P:Calorie ME[c,d]	g/Mcal	1.31
Analyzed Ca:Analyzed P[e]	Ratio	1.50
Sodium[f]	%	0.22
Chloride	%	0.22
Added trace minerals[g]		
Zinc	ppm	125
Iron	ppm	100
Manganese	ppm	50
Copper	ppm	15
Iodine	ppm	0.35
Selenium[h]	ppm	0.30
Added vitamins[g,i]	**per kg diet**	
Vitamin A	IU/kg	9920
Vitamin D	IU/kg	1985
Vitamin E	IU/kg	66
Vitamin K	mg/kg	4.4
Choline[j]	mg/kg	660
Niacin	mg/kg	44
Riboflavin	mg/kg	10
Pantothenic acid	mg/kg	33

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ITEM[a]	UNIT	
Added vitamins[g,i]	**per kg diet**	
Vitamin B_{12}	mcg/kg	37
Folic Acid	mcg/kg	1325
Biotin	mcg/kg	220
Thiamine	mg/kg	2.2
Pyridoxine	mg/kg	3.3
Recommended specifications		
Neutral detergent fiber (NDF), min.	%	11
Linoleic acid	%	1.9

[a]These specifications are based on nutrient intake per day and should be used as a guideline. They require adjustment for feed intake, local conditions, legislation, and markets. They require adjustment for feed intake, local conditions, and markets. Click here to access the PIC® Optimum Boar Feeding tool to adjust the nutrient specifications based on dietary energy concentration.

[b]L-Lys-HCl maximum inclusions are suggested based on corn and soybean meal-based diets and are to be used as a guideline. Inclusion rates above the suggested maximum levels could be used as long as all other amino acid to Lys ratios meet PIC® recommendations.

[c]Phosphorus values are considering release due to phytase; however, release values need to be based on suppliers' recommendation established from peer-reviewed scientific research. STTD P = Standardized total tract digestible phosphorus; Av. P = available phosphorus.

[d]The requirements for available P are estimated as 95% of the STTD P recommendations in a corn-soybean meal boar stud diet with supplemental phytase, using STTD P coefficient and P bioavailability from NRC (1998 and 2012).

[e]If the boar stud diet is formulated without the inclusion of phytase, the recommended analyzed Ca:analyzed P ratio is 1.25.

[f]If sodium levels are not known in major ingredients use at least 80% of sodium coming from sodium chloride.

[g]The values represent micronutrient supplementation without giving credit for ingredient content.

[h]Organic selenium is commonly used for boar diets. However, evidence for benefits compared to inorganic supplementation is limited.

[i]Pelleting and (or) expanding decreases vitamin stability by 10-12% and 15-20% respectively. Consult vitamin manufacturer to verify their specific vitamin stability under pelleting conditions so additional fortification can be made as required.

[j]Assuming a typical corn and soybean meal-based diet provides 1325 mg per kg.

PIC® Nutrient Specifications for Developing Gilts (As-Fed)

ITEM[a]	UNIT	Body weight, kg		
		23 to 60	60 to 90	90 to Breeding[b]
Standardized ileal digestible amino acids				
Lys:Calorie NE[c]	g/Mcal	4.29	3.46	2.51
Lys:Calorie ME[c]	g/Mcal	3.15	2.57	1.86
Methionine + Cysteine:Lys	Ratio	58	58	58
Threonine:Lys	Ratio	65	65	66
Tryptophan:Lys	Ratio	18	18	18
Valine:Lys	Ratio	68	68	68
Isoleucine:Lys	Ratio	56	56	56
Leucine:Lys	Ratio	101	101	102
Histidine:Lys	Ratio	34	34	34
Phenylalanine + Tyrosine:Lys	Ratio	94	95	96
L-Lys-HCl, max.[d]	%	0.40	0.32	0.27
Minerals				
STTD P:Calorie NE[e]	g/Mcal	1.64	1.37	1.09
STTD P:Calorie ME[e]	g/Mcal	1.23	1.04	0.84
Av. P:Calorie NE[e,f]	g/Mcal	1.41	1.17	0.94
Av. P:Calorie ME[e,f]	g/Mcal	1.05	0.89	0.73
Analyzed Ca:Analyzed P, range[g]	Ratio	1.25 - 1.50	1.25 - 1.50	1.25 - 1.50
Sodium[h]	%	0.25	0.25	0.25
Chloride	%	0.25	0.25	0.25
Added trace minerals[i]				
Zinc	ppm	125	125	125
Iron	ppm	100	100	100
Manganese	ppm	50	50	50
Copper	ppm	15	15	15
Iodine	ppm	0.35	0.35	0.35
Selenium	ppm	0.30	0.30	0.30
Added vitamins[i,j]	**per kg diet**			
Vitamin A	IU/kg	9920	9920	9920
Vitamin D	IU/kg	1985	1985	1985
Vitamin E	IU/kg	66	66	66
Vitamin K	mg/kg	4.4	4.4	4.4
Choline[k]	mg/kg	660	660	660
Niacin	mg/kg	44	44	44

ITEM[a]	UNIT	Body weight, kg		
		23 to 60	60 to 90	90 to Breeding[b]
Added vitamins[i,j]	**per kg diet**			
Riboflavin	mg/kg	9.9	9.9	9.9
Pantothenic acid	mg/kg	33	33	33
Vitamin B_{12}	mcg/kg	37	37	37
Folic Acid	mcg/kg	1325	1325	1325
Biotin	mcg/kg	220	220	220
Thiamine	mg/kg	2.2	2.2	2.2
Pyridoxine	mg/kg	3.3	3.3	3.3

[a]These guidelines are based on a 3-phase gilt development program. The number of phases and body weight ranges can be varied. These specifications are based on nutrient intake per day and should be used as a guideline. They require adjustment for feed intake, local conditions, legislation, and markets. Click here to access the PIC® Recommendations for Developing Gilts tool for nutrient recommendations according to your specific feeding program.

[b]After approximately 90 kg of body weight, feed a gestation diet to avoid having to manufacture another specialized gilt development diet.

[c]Please click here to access the PIC® Nutrient Recommendations for Developing Gilts tool to obtain the recommended SID Lys to energy ratio to your specific situation.

[d]L-Lys-HCl maximum inclusions are suggested based on corn and soybean meal-based diets and are to be used as a guideline. Inclusion rates above the suggested maximum levels could be used as long as all other amino acid to Lys ratios meet PIC® recommendations.

[e]Phosphorus values are considering release due to phytase; however, release values need to be based on suppliers' recommendation established from peer-reviewed scientific research. STTD P = Standardized total tract digestible phosphorus; Av. P = available P.

[f]The recommendations for available P are estimated as 86% of the STTD P recommendations in a corn-soybean meal-gilt development-diet using STTD P coefficient and P bioavailability from NRC (1998 and 2012). Please go to the PIC® Nutrient Recommendations for Developing Gilts tool to obtain the recommended STTD P or Av. P to energy ratio to your specific situation.

[g]The analyzed Ca:analyzed P ratio is determined based on Vier et al., (2019c) considering P levels at PIC® requirement.

[h]If sodium levels are not known in major ingredients use at least 80% of sodium coming from sodium chloride.

[i]The values represent micronutrient supplementation without giving credit for ingredient content. The added vitamin and trace mineral (VTM) recommendations are identical to sow levels. However, if sow-level of VTM is not available, the VTM levels recommended for commercial pigs can be used for developing gilts up to 60 kg.

[j]Pelleting and (or) expanding decreases vitamin stability by 10-12% and 15-20% respectively. Consult vitamin manufacturer to verify their specific vitamin stability under pelleting conditions so additional fortification can be made as required.

[k]Assuming a typical corn and soybean meal-based diet provides 1325 mg per kg.

PIC® Nutrient Specifications for Gestating Gilts and Sows (As Fed)

ITEM[a]	UNIT		
Daily energy intake[b]		**NE**	**ME**
Fat sows	Mcal/d	3.7	4.9
Gilts[c] and ideal sows	Mcal/d	4.4	5.9
Thin sows	Mcal/d	6.1	8.0
Estimated caliper change[d]			
Fat, throughout gestation	units	-1.0	
Ideal, throughout gestation	units	1.7	
Thin, for an average of 30-day period	units	2.0	
Standardized ileal digestible amino acids			
Lys, min	g/d	11.0	
Methionine + Cysteine:Lys	Ratio	70	
Threonine:Lys	Ratio	76	
Tryptophan:Lys	Ratio	19	
Valine:Lys	Ratio	71	
Isoleucine:Lys	Ratio	58	
Leucine:Lys	Ratio	92	
Histidine:Lys	Ratio	35	
Phenylalanine + Tyrosine:Lys	Ratio	96	
L-Lys-HCl, max.[e]	%	0.25	
Minerals			
STTD P:Calorie NE[f]	g/Mcal	1.84	
STTD P:Calorie ME[f]	g/Mcal	1.36	
Av. P:Calorie NE[f,g]	g/Mcal	1.74	
Av. P:Calorie ME[f,g]	g/Mcal	1.29	
Analyzed Ca:Analyzed P[h]	Ratio	1.50	
Sodium[i]	%	0.24	
Chloride	%	0.24	
Added trace minerals[j]			
Zinc	ppm	125	
Iron	ppm	100	
Manganese	ppm	50	
Copper	ppm	15	
Iodine	ppm	0.35	
Selenium	ppm	0.30	

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ITEM[a]	UNIT	
Added vitamins[j,k]	**per kg diet**	
Vitamin A	IU/kg	9920
Vitamin D	IU/kg	1985
Vitamin E	IU/kg	66
Vitamin K	mg/kg	4.4
Choline[l]	mg/kg	660
Niacin	mg/kg	44
Riboflavin	mg/kg	10
Pantothenic acid	mg/kg	33
Vitamin B_{12}	mcg/kg	37
Folic Acid	mcg/kg	1325
Biotin	mcg/kg	220
Thiamine	mg/kg	2.2
Pyridoxine	mg/kg	3.3

[a]These specifications are based on nutrient intake per day and should be used as a guideline. They require adjustment for feed intake, local conditions, legislation, and markets. Click here to access Dynamic Feeding Program for PIC® Females tool to adjust the nutrient specification based on dietary energy concentration. Be aware that sows housed below their thermal neutral zone require more energy.

[b]Net energy (NE) was estimated using a conversion factor of 0.75 from metabolizable energy (ME). For different diet compositions this may vary (i.e., 0.73 to 0.76) depending on the ingredients used. If gestation diets are pelleted, consider 3% reduction of feed allowance.

[c]PIC® recommends energy allowance of 4.4 Mcal NE/d or 5.9 Mcal ME/d for gilts throughout the entire gestation regardless of body condition.

[d]The estimated caliper score change is based on a sow herd assuming an average body weight of 200 kg. The regression equation was reported by Knauer et al., (2020): caliper score change per day = 1.35 × (ME intake, Mcal/d) ÷ (Body weight, kg)$^{0.75}$ – 0.1332.

[e]L-Lysine-HCl maximum inclusions are suggested based on corn and soybean meal-based diets and are to be used as a guideline. Inclusion rates above the suggested maximum levels could be used as long as all other amino acid to Lys ratios meet PIC® recommendations.

[f]Phosphorus values are considering release due to phytase; however, release values need to be based on suppliers' recommendation established from peer-reviewed scientific research. STTD P = Standardized total tract digestible phosphorus. Av. P = available phosphorus.

[g]The requirements for Av. P are estimated as 95% of the STTD P recommendations in a corn-soybean meal gestation diet with supplemental phytase, using STTD P coefficient and P bioavailability from NRC (1998 and 2012).

[h]If the gestation diet is formulated without the inclusion of phytase, the recommended analyzed Ca:analyzed P ratio is 1.25.

[i]If sodium levels are not known in major ingredients use at least 80% of sodium coming from sodium chloride.

[j]The values represent micronutrients supplementation without giving credit for ingredient content.

[k]Pelleting and (or) expanding decreases vitamin stability by 10-12% and 15-20% respectively. Consult vitamin manufacturer to verify their specific vitamin stability under pelleting conditions so additional fortification can be made as required.

[l]Assuming a typical corn and soybean meal-based diet provides 1325 mg per kg.

Section P

PIC® Nutrient Specifications for Lactating Gilts and Sows (As-Fed)

ITEM[a]	UNIT	GILTS	SOWS	HERD
Net weight body loss[b]	%	<10	<10	<10
Fat loss, Max[b]	mm	0-2	0-2	0-2
Expected caliper loss[c]	units	---	---	2.3
Litter growth[d]	kg/d	2.5	2.7	2.7
Daily net energy (NE) intake[e,f]	Mcal/d	12.5	15.5	14.9
Daily metabolizable energy (ME) intake[f]	Mcal/d	16.9	20.9	20.1
Average feed intake[d,g]	kg/d	5.0	6.2	6.0
Standardized ileal digestible amino acids				
Daily Lys intake, single lactation diet	g/d	50.0	62.0	59.5
Daily Lys intake, two lactation diets[h]	g/d	59.0	56.5	---
Methionine + Cysteine:Lys	Ratio	53	53	53
Threonine:Lys	Ratio	64	64	64
Tryptophan:Lys	Ratio	19	19	19
Valine:Lys	Ratio	64	64	64
Isoleucine:Lys	Ratio	56	56	56
Leucine:Lys	Ratio	114	114	114
Histidine:Lys	Ratio	40	40	40
Phenylalanine + Tyrosine:Lys	Ratio	113	113	113
L-Lys-HCl, max.[i]	%	0.45	0.45	0.45
Minerals				
STTD P:Calorie NE[j]	g/Mcal	1.90	1.67	1.72
STTD P:Calorie ME[j]	g/Mcal	1.44	1.27	1.30
Av. P:Calorie NE[j,k]	g/Mcal	1.73	1.52	1.56
Av. P:Calorie ME[j,k]	g/Mcal	1.31	1.15	1.19
Analyzed Ca:Analyzed P[l]	Ratio	1.50	1.50	1.50
Sodium[m]	%	0.27	0.23	0.24
Chloride	%	0.27	0.23	0.24
Added trace minerals[n]				
Zinc	ppm	125	125	125
Iron	ppm	100	100	100
Manganese	ppm	50	50	50
Copper	ppm	15	15	15
Iodine	ppm	0.35	0.35	0.35
Selenium	ppm	0.30	0.30	0.30

ITEM[a]	UNIT	GILTS	SOWS	HERD
Added vitamins[n,o]	**per kg diet**			
Vitamin A	IU/kg	9920	9920	9920
Vitamin D	IU/kg	1985	1985	1985
Vitamin E	IU/kg	66	66	66
Vitamin K	mg/kg	4.4	4.4	4.4
Choline[p]	mg/kg	660	660	660
Niacin	mg/kg	44	44	44
Riboflavin	mg/kg	10	10	10
Pantothenic acid	mg/kg	33	33	33
Vitamin B_{12}	mcg/kg	37	37	37
Folic Acid	mcg/kg	1325	1325	1325
Biotin	mcg/kg	220	220	220
Thiamine	mg/kg	2.2	2.2	2.2
Pyridoxine	mg/kg	3.3	3.3	3.3

[a]These specifications are based on nutrient intake per day and should be used as a guideline. They require adjustment for feed intake, local conditions, legislation, and markets.

[b]Assumptions: Gilt - 135 kg body weight (BW) at breeding and 35 kg net maternal gain; Sow – 180 kg BW at breeding and 9 kg net maternal gain; Post-farrowing weight of 175 kg; Weight loss of 10 kg.

[c]Expected caliper loss is estimated based on units of caliper measured at farrowing according to data collected at a 4,500 sow farm unit in Spain (Huerta et al., 2021). Regression equation if using the old version of the caliper: Caliper unit loss = 6.253704 + (-0.874766 × CaliperFarrow) + (0.042414 × CaliperFarrow^2). Regression equation if using the new version of the caliper: Caliper unit loss = 6.253704 + [-0.874766 × (CaliperFarrow + 4)] + [0.042414 × $(\text{CaliperFarrow} + 4)^2$].

[d]Assuming parity structure of 20% gilts and 80% sows.

[e]Net energy was estimated using a conversion factor of 0.74 from metabolizable energy. For different diet compositions this may vary (i.e., 0.73 to 0.76) depending on the ingredients used.

[f]Energy intake per day is only a reference and does not represent a recommendation.

[g]Average daily feed intake is only a reference for a 21-d lactation and does not represent a recommendation. It assumes gilts are eating on average 19% less than sows. Please click here to access a Dynamic Feeding Program for PIC® Females tool to adjust the nutrient specifications based on the average lactation feed intake.

[h]In situations where a gilt-specific lactation diet is applicable, such as parity segregation or startups, consider feeding 59.0 g of SID Lys per day for primiparous sows for maximum lactation performance; and feeding 56.5 g of SID Lys per day for multiparous sows for improved cost-effectiveness.

[i]L-Lys-HCl maximum inclusions are recommended based on corn and soybean meal-based diets and are to be used as a guideline. There should be no constraint on including synthetic amino acids in diets as long as there are no other limiting nutrients. Soybean meal inclusions of over 30% have shown to reduce lactation feed intake (Gourley et al., 2020c).

[j]Phosphorus values are considering release due to phytase; however, release values need to be based on suppliers' recommendation established from peer-reviewed scientific research. STTD P = Standardized total tract digestible phosphorus. Av. P = available phosphorus.

[k]The requirements for Av. P are estimated as 90% of the STTD P recommendations in a corn-soybean meal lactation diet with supplemental phytase, using STTD P coefficient and P bioavailability from NRC (1998 and 2012).

[l]If the lactation diet is formulated without the inclusion of phytase, the recommended analyzed Ca:analyzed P ratio is 1.25.

[m]If sodium levels are not known in major ingredients use at least 80% of sodium coming from sodium chloride.

[n]The values represent micronutrient supplementation without giving credit for ingredient content.

[o]Pelleting and (or) expanding decreases vitamin stability by 10-12% and 15-20% respectively. Consult vitamin manufacturer to verify their specific vitamin stability under pelleting conditions so additional fortification can be made as required.

[p]Assuming a typical corn and soybean meal-based diet provides 1325 mg per kg.

PIC® Nutrient Specifications for Prestart Pigs (As-Fed)

ITEM[a]	UNIT	Body Weight, kg	
		Weaning to ~7.5	~7.5 to 11.5
Dietary energy level (Based on NRC 2012 ingredient values)			
Net energy[b,c]	kcal/kg	2545	2545
Metabolizable energy[b]	kcal/kg	3395	3395
Standardized ileal digestible amino acids			
Lys[d]	%	1.46	1.42
Methionine + Cysteine:Lys	Ratio	58	58
Threonine:Lys	Ratio	65	65
Tryptophan:Lys	Ratio	20	19
Valine:Lys	Ratio	67	67
Isoleucine:Lys[e]	Ratio	55	55
Leucine:Lys	Ratio	100	100
Histidine:Lys	Ratio	32	32
Phenylalanine + Tyrosine:Lys	Ratio	92	92
Minerals			
Av. phosphorus[f,g]	%	0.45	0.40
STTD phosphorus[f,g]	%	0.50	0.45
Analyzed calcium[g]	%	0.65	0.65
Sodium[h]	%	0.40	0.35
Chloride	%	0.35 - 0.40	0.32
Added trace minerals[i]			
Zinc[j]	ppm	130	130
Iron[k]	ppm	130	130
Manganese	ppm	50	50
Copper[l]	ppm	18	18
Iodine	ppm	0.65	0.65
Selenium	ppm	0.30	0.30
Added vitamins[i,m]	**per kg diet**		
Vitamin A	IU/kg	5000	5000
Vitamin D	IU/kg	1600	1600
Vitamin E	IU/kg	50	50
Vitamin K	mg/kg	3.0	3.0
Choline[n]	mg/kg	---	---
Niacin	mg/kg	50	50
Riboflavin	mg/kg	8.0	8.0
Pantothenic acid	mg/kg	28	28
Vitamin B_{12}	mcg/kg	38	38

Metric Version 2021.04.14
For the most updated PIC® Nutrition and Feeding Guidelines visit https://www.pic.com/resources/nutrition

ITEM[a]	UNIT	Body Weight, kg	
		Weaning to ~7.5	~7.5 to 11.5
Recommended specifications			
Soybean meal, max[o]	%	20	28
SID Lys:Crude protein, max[p]	%	6.4	6.4
Highly digestible protein[q]	%	5 - 10	3 - 5
Highly digestible carbohydrate[r]	%	15.0	7.5

[a]These specifications are based on nutrient intake per day and should be used as a guideline. They require adjustment for feed intake, local conditions, legislation, and markets.

[b]Energy levels are guidelines and should be adjusted according to market price and specific farm scenario.

[c]Net energy was estimated using a conversion factor of 0.75 from metabolizable energy. For different diet compositions this may vary (i.e., 0.73 to 0.76) depending on the ingredients used.

[d]The minimum dietary SID Lys level for 5.5 to 11.5 kg pigs is 1.35% if dietary SID Lys in the late nursery phase meets PIC® recommendation.

[e]Diet with < 2% blood cells. If greater than 2% blood cells the SID Isoleucine:Lys ratio should be 60.

[f]Av. phosphorus = available phosphorus; STTD phosphorus = Standardized total tract digestible phosphorus.

[g]Calcium and phosphorus release values from phytase should be considered only if enough substrate is available based on diet formulation.

[h]If sodium levels are not known in major ingredients use at least 80% of sodium coming from sodium chloride.

[i]The values represent micronutrient supplementation without giving credit for ingredient content.

[j]Maximum duration from weaning to 11.5 kg or 42 d of age. Pharmacological levels of zinc to improve growth performance follow: < 7.5 kg use 3000 ppm; and for 17.5-11.5 kg use 2000 ppm. Different countries have different regulations regarding the use of pharmacological levels zinc, follow your country's regulation.

[k]Maximum supplemental iron is 200 ppm because of the substantial iron content of di-calcium phosphate and because high iron intake encourages E. coli proliferation in the young pig.

[l]Supplemental copper up to 250 ppm could be used to improve growth performance if pharmacological Zn levels are not allowed. Inorganic forms assumed. Different countries have different regulations regarding the use of copper as growth promoter, please follow your country's regulation.

[m]Pelleting and (or) expanding decreases vitamin stability by 10-12% and 15-20% repectively. Consult vitamin manufacturer to verify their specific vitamin stability under pelleting conditions so additional modification can be made as required.

[n]A total level of 1325 mg of choline per kg should be achieved.

[o]Suggested levels for commercial production and good to high health. High health pigs can tolerate higher levels of SBM (30% for 7.5-11.5 kg).

[p]Based on the results of Millet et al. (2018).

[q]For example, high quality fish meal, animal plasma, blood meal, enzymatically treated soybean meal, etc.;

[r]The most common highly digestible carbohydrate source is edible-grade lactose. Other highly digestible carbohydrates source can replace part of lactose if economical (i.e., maltose, dextrose, micronized corn, micronized rice, maltodextrin, etc.).

Section R

PIC® Nutrient Specifications for Late Nursery and Grow-Finish Gilts and Barrows (As-Fed)

ITEM[a]	UNIT	Body Weight, kg							
		11 - 23	23 - 41	41 - 59	59 - 82	82 - 104	104 - Market	104-Market with Ractopamine[r] < 21 D	104-Market with Ractopamine[r] > 21 D
Standardized Ileal Digestible amino acids									
Lys:Calorie NE[b]	g/Mcal	5.32	4.74	4.11	3.54	3.06	2.72	3.92	3.81
Lys:Calorie ME[b]	g/Mcal	3.90	3.47	3.03	2.62	2.29	2.08	2.99	2.91
Methionine + cysteine:Lys	Ratio	58	58	58	58	58	58	58	58
Threonine:Lys	Ratio	65	65	65	65	65	66	68	68
Tryptophan:Lys[c]	Ratio	19	18	18	18	18	18	20	20
Valine:Lys	Ratio	68	68	68	68	68	68	68	68
Isoleucine:Lys	Ratio	55	56	56	56	56	56	56	56
Leucine:Lys[d]	Ratio	100	101	101	101	101	102	100	100
Histidine:Lys	Ratio	32	34	34	34	34	34	33	33
Phenylalanine + tyrosine:Lys	Ratio	92	94	94	94	95	96	94	95
L-Lys-HCl, max[e]	%	---[f]	0.45	0.40	0.35	0.28	0.25	0.45	0.45
Max. SID Lys:CP[g]	Ratio	6.4	---	---	---	---	---	---	---
Min. crude protein[h]	%	---	---	---	---	---	13	---	---
Minerals									
STTD P:Calorie NE[i,j]	g/Mcal	1.80	1.62	1.43	1.25	1.10	0.99	1.20	1.16
STTD P:Calorie ME[i,j]	g/Mcal	1.32	1.20	1.07	0.95	0.84	0.77	0.93	0.90
Av. P:Calorie NE[i,j,k]	g/Mcal	1.54	1.39	1.23	1.07	0.94	0.85	0.99	0.96
Av. P:Calorie ME[i,j,k]	g/Mcal	1.14	1.03	0.92	0.82	0.72	0.66	0.77	0.74
Analyzed Ca:Analyzed P, range[l]	Ratio	1.25-1.50	1.25-1.50	1.25-1.50	1.25-1.50	1.25-1.50	1.25-1.50	1.25-1.50	1.25-1.50
Sodium[m]	%	0.28	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Chloride	%	0.32	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Added trace minerals[n]									
Zinc	ppm	130	111	98	78	65	65	65	65
Iron	ppm	130	111	98	78	65	65	65	65
Manganese	ppm	50	43	38	30	25	25	25	25
Copper[o]	ppm	18	15	14	11	9	9	9	9
Iodine	ppm	0.65	0.55	0.49	0.39	0.33	0.33	0.33	0.33
Selenium	ppm	0.30	0.30	0.30	0.30	0.25	0.25	0.25	0.25

ITEM[a]	UNIT	Body Weight, kg							
		11 - 23	23 - 41	41 - 59	59 - 82	82 - 104	104 - Market	104-Market with Ractopamine[r] < 21 D	104-Market with Ractopamine[r] > 21 D
Added vitamins[n,p]	**per kg diet**								
Vitamin A	IU/kg	5000	4250	3750	3000	2500	2500	2500	2500
Vitamin D	IU/kg	1600	1360	1200	960	800	800	800	800
Vitamin E	IU/kg	51	44	37	31	26	26	26	26
Vitamin K	mg/kg	3.1	2.6	2.4	1.8	1.5	1.5	1.5	1.5
Niacin	mg/kg	51	44	37	31	26	26	26	26
Riboflavin	mg/kg	8	7	7	4	4	4	4	4
Pantothenic acid	mg/kg	28	24	22	18	14	14	14	14
Vitamin B_{12}	mcg/kg	38	33	29	22	20	20	20	20
Choline[q]	mg/kg	---	---	---	---	---	---	---	---

[a]These specifications are based on nutrient intake per day and should be used as a guideline. They require adjustment for feed intake, local conditions, legislation, and markets.

[b]For more detailed information on the equations to determine the Lys recommendations, refer to Section C. Please click here to access the PIC® SID Lys Biological and Economical tools to determine the SID Lys to energy ratio to maximize performance and/or economics based on your specific situation. These tools also provide SID Lys to energy ratios to maximize performance for barrows, gilts, and intact boars. The SID Lys to energy ratios meet the biological requirements for PIC® 327, 337, and 359 sired pigs. PIC® suggests to utilize 99% of the tool estimates for PIC® 380, 408, and 410 sired pigs; and 97% for PIC® 800 sired pigs to achieve the biological requirements of these sirelines.

[c]Please click here to access the Tryptophan:Lys Economic Model for Nursery and Finishing Pigs tool to determine the SID tryptophan to Lys ratio to maximize performance and/or economics based on your specific situation.

[d]Excess SID leucine to Lys ratio can negatively impact pig growth performance. Please see the table on page R-3 for adjustments in tryptophan, valine, and isoleucine to Lys ratios according to leucine to Lys ratio (Adapted from Cemin et al., 2019).

[e]L-Lys-HCl maximum inclusions are suggested based on corn and soybean meal-based diets and are to be used as a guideline. Inclusion rates above the suggested maximum levels could be used as long as all other amino acid to Lys ratios meet PIC® recommendations.

[f]High health 11-23 kg pigs can tolerate higher levels of soybean meal up to 35%.

[g]Based on the results of Millet et al. (2018).

[h]These recommendations are based on a series of studies conducted by Soto et al. (2019b). Assumes all amino acid ratios are adequate.

[i]Phosphorus values are considering release due to phytase; however, release values need to be based on suppliers' recommendation established from peer-reviewed scientific research. STTD P = Standardized total tract digestible phosphorus, Av. P = available P.

[j]For more detailed information on the equations to determine the phosphorus recommendations, refer to Section D. Please click here to access the PIC® STTD and Av. P Biological and Economical tools to determine the phosphorus to energy ratio to maximize performance and/or economics based on your specific situation.

[k]The recommendations for available P are estimated as 86% of the STTD P recommendations in a corn-soybean meal-diet using STTD P coefficient and P bioavailability from NRC (1998 and 2012).

[l]The analyzed Ca:analyzed P ratio is determined based on Vier et al., (2019c) considering P concentrations at the recommended PIC® requirement.

[m]If sodium levels are not known in major ingredients use at least 80% of sodium coming from sodium chloride.

[n]The values represent micronutrients supplementation without giving credit for ingredient content.

[o]High levels of copper to improve growth performance is 250 ppm for 11-23 kg pigs. Inorganic forms assumed. Different countries have different regulations regarding the use of copper as a growth promoter, follow your country's regulation.

[p]Thermal processing by pelleting decreases vitamin stability by 10-12% and expanding by 15-20%. Consult vitamin manufacturers to verify their specific vitamin stability underthermal processing conditions so additional fortification can be made as required.

[q]For 11-23 kg pigs, a total concentration of 1325 mg of choline per kg including choline provided by ingredients.

[r]When usage is allowed by the local governing body within your country of operation.

Example of Adjustments on Tryptophan, Valine, and Isoleucine Ratios According to Leucine Levels (adapted from Cemin et al., 2019)

Item	Leucine:Lys Ratio								
	125.0	135.0	145.0	155.0	165.0	175.0	185.0	195.0	205.0
Tryptophan	18.0	18.2	18.5	18.7	19.0	19.2	19.4	19.7	19.9
Valine	68.0	68.4	69.7	71.1	72.4	73.8	75.1	76.5	77.8
Isoleucine	56.0	56.0	56.0	56.0	56.2	57.2	58.2	59.3	60.3

Section S

Feeding PIC® Pigs within Special Topics

Adjustments can be made to PIC® nutrition and feeding recommendations to accommodate special topics of pig production, which include specific regional legislation, different production environments, or different packing plant requirements.

For information regarding feeding PIC® pigs under specific programs reach out to your PIC® account team or click here:

- Carcass yield and pork fat quality
- Contingent considerations for urgent situations
- Feed additives
  - Key points to consider when using Ractopamine in swine diets
- Feeding pigs in hot environments
- Feed manufacturing guidelines for PIC® pigs
- Ham production
- Immunocastrated pigs
- Intact finishing boar's requirements
- Liquid feeding
- Nutritional factors associated with abnormal behaviors
- Outdoor production
- Split sex feeding
- Upper limits for feed ingredients use
- Water

Section T

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Section U

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