Swine Nutrition

By H.H. STEIN*

THE National Research Council (NRC) provides estimates of nutrient requirements for all phases of pig production (updated in 2012). These estimates do not contain safety factors to allow for variations in pig requirements, variations in the level or availability of nutrients in feed ingredients or a loss of vitamin potency during processing and storage.

It is also recognized that, under certain circumstances, nutrient requirements may be greater than those recommended by NRC. That may be the case if high-fiber diets are fed to pigs, because the requirement for digestible threonine increases as a consequence of feeding high-fiber diets or if pigs are under chronic disease pressure, which may elevate the requirement of certain nutrients.

It is, therefore, not unusual to include some nutrients, especially vitamins and micro-minerals, at concentrations greater than the requirement estimates published by NRC (2012).

Nutrient, energy requirements

Diets fed to pigs usually contain five of the six classes of nutrients, i.e., carbohydrates, lipids, minerals, protein, water and vitamins. Water is usually provided on an *ad libitum* basis from water nipples to all categories of pigs, but the remaining five classes of nutrients are included in the dry portion of the diet.

Pigs have specific needs for amino acids (from the protein fraction), fatty acids (from the lipids), vitamins and minerals. In contrast, pigs do not have specific needs for carbohydrates, but it is common to feed relatively large quantities of carbohydrates to pigs in the form of starch and fiber. Pigs also have requirements for energy, and diets are usually formulated to contain a specific concentration of digestible or metabolizable energy.

Diets may also contain non-nutritive feed additives such as acidifiers, probiotics, exogenous enzymes and others. The use of antibiotic growth promoters was once common in diets for weanling and growing/finishing pigs, but the recent change in the labeling of most of these antibiotics has greatly reduced the use of antibiotic growth promoters in diets for pigs.

Energy. Energy is needed for all productive functions in the body. Energy in feed ingredients and diets is supplied by protein, fat and carbohydrates. The pig will use the majority of dietary protein to synthesize body protein that will be deposited in muscles and other tissues. If there is more protein in the diet than needed to maximize protein synthesis, the excess amino acids will be deaminated, the nitrogen will be excreted in the urine and the remaining part of the amino acids will be utilized for energy in the form of ATP or stored as fat. Dietary fat may also be directly stored in the adipose tissue of pigs and in other tissues — or fat may be oxidized and used to synthesize ATP that the pig needs for maintenance energy. The carbohydrates in the diets are primarily used for ATP synthesis, and any excess carbohydrates that are not needed for ATP synthesis will be used to synthesize fat that will be deposited in the body. A small portion of the carbohydrates may also be stored as glycogen in the liver or skeletal muscles, but quantitatively, this is a minor amount of energy, and almost all excess energy is stored as fat. The concentration of energy is greater in lipids than in carbohydrates and amino acids, and including high concentrations of lipids in the diets, therefore, often results in the formulation of high-energy diets (Figure 1).

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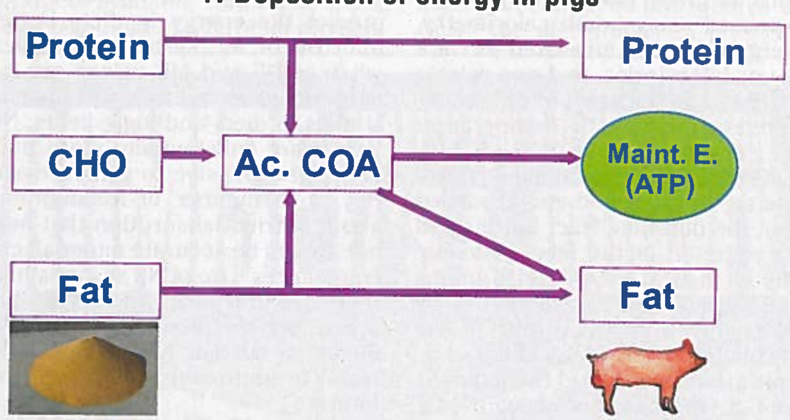
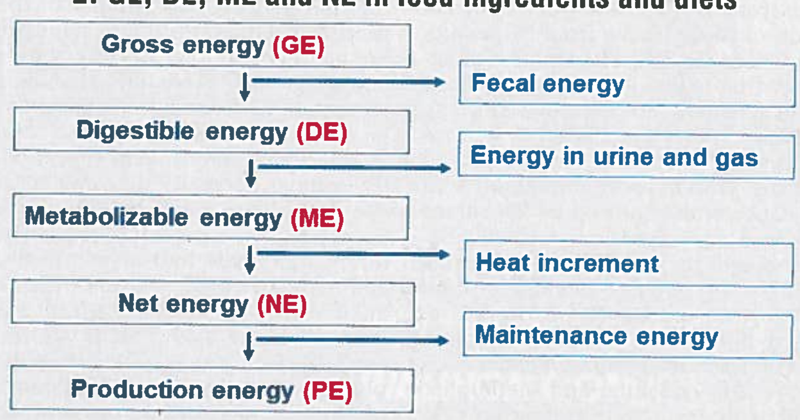
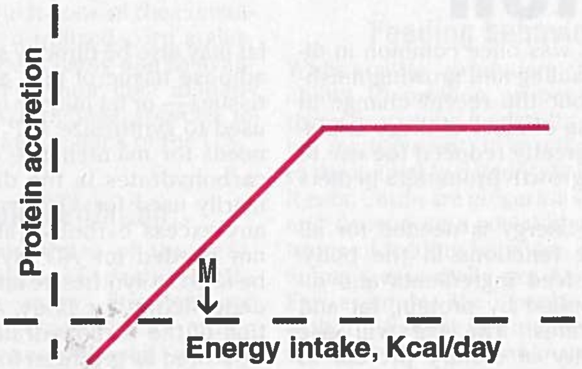
1. Deposition of energy in pigs



2. GE, DE, ME and NE in feed ingredients and diets



3. Protein accretion versus digestible energy intake



An energy system expresses the energy requirements of the body and the energy supplied by feeds in the same units. The energy systems commonly used in swine nutrition are digestible energy (DE), metabolizable energy (ME) and net energy (NE). Each of these systems has advantages and disadvantages (Figure 2).

The total amount of energy in feedstuffs is gross energy (GE) and is measured using bomb calorimetry. Energy is usually measured as calories or kilocalories, and one calorie is defined as the amount of heat required to increase the temperature of 1 g of water from 16.5°C to 17.5°C. Some of the energy-containing nutrients are not digested and absorbed from the digestive tract but instead are excreted in the feces, and the amount of fecal energy varies among feed ingredients. Subtraction of fecal energy from GE results in the calculation of DE. Many energy systems around the world (including in the U.S.) are based on using the DE or ME of feed ingredients.

Some energy is also excreted in urine, and some is lost as methane gas from the digestive tract. Subtraction of these losses from DE results in values for ME. The amount of energy that is lost in methane is small and is usually not measured. Energy lost in urine is associated with nitrogen excretion and is closely related to the protein level and amino acid balance of the entire diet. ME values of feed ingredients are routinely determined and used in diet formulation. Many energy systems around the world are based on the ME of feed ingredients, and diets are often formulated using this system.

As pigs consume and metabolize nutrients from their diets, they generate heat, which is lost and, therefore, cannot be used for production. The heat lost is greater from fiber than from lipids, starch and amino acids, and different diets may, therefore, result in different amounts of heat lost. To account for these losses, the NE of diets and feed ingredients is sometimes calculated, so some energy systems are based on the NE of ingredients rather than DE or ME.

Theoretically, NE systems will predict the energy in diets better than DE or ME systems. However, whereas DE and ME values can be determined in routine metabolism studies in diets and ingredients, NE values are substantially more difficult and expensive to generate and rely on a number of assumptions about nutrient absorption that may not always be accurate under all circumstances. Use of NE systems has, therefore, not been universally adopted, but it is likely that improvements to current NE systems may result in improved accuracy in the future.

Amino acids. The amino acid supply from the diet is determined largely by the amino acid composition of the diet and the digestibility of the protein in which the amino acids are bound. Protein digestibility varies enough among feedstuffs that it is important to formulate diets on the basis of digestible rather than total amino acids. Amino acid digestibility is most correctly determined at the end of the small intestine (the ileum) because the microbes in the hindgut degrade and/or synthesize amino acids; also, because amino acids cannot be absorbed from the hindgut, these amino acids are not available for protein synthesis in the pig. However, to avoid the influence of hindgut microbes on the estimated values for digestible amino acids, values for "ileal digestibility" need to be determined. These values are obtained after surgically installing a cannula in the distal small intestine of the pig and collecting intestinal fluids over several days, which allows the apparent ileal digestibility of individual amino acids to be calculated.

Measures of apparent digestibility always show low values for a few key amino acids (threonine, tryptophan and cysteine) because they are in high concentrations in endogenous proteins. As a result, values for apparent ileal digestibility for amino acids in individual feed ingredients are not always additive in mixed diets, so it is not always possible to predict the concentration of apparent digestible amino acids in mixed diets based on values obtained in individual ingredients. However, if values for apparent ileal digestibility of amino acids are corrected for basal endogenous losses — determined using a protein-free diet — then values for standardized ileal digestibility of amino acids are calculated, and these values are additive in mixed diets. As a consequence, diets for pigs should always be formulated based on values for standardized ileal digestibility.

The pig requires an adequate dietary supply of the 10 indispensable amino acids. Independently estimating requirements for each of these 10 amino acids under varying conditions is a daunting task. However, a more practical approach involves determining the requirements for lysine and then calculating the requirements of the other amino acids using the concept of "ideal protein." This concept relies on the assumption that the amino acid requirements for a specific group of pigs are constant and, therefore, can be calculated from the requirement for lysine. As a consequence, only the requirement for lysine is determined empirically, whereas the requirements for all other amino acids are calculated. However, as mentioned earlier, if high-fiber diets are fed or if pigs are under chronic immune challenges, the requirement for certain amino acids may increase, and the assumptions for ideal protein may not be completely correct. Results of recent research also highlighted the negative effects of excess leucine in diets for pigs. Excess leucine can sometimes not be avoided if large quantities of corn protein or sorghum protein are used in the diets, which will be the case in diets based on dried distillers grains plus solubles (DDGS) or corn gluten meal. In those cases, the concentration of dietary leucine may be close to twice as high as the requirement, and this will result in reduced feed intake and reduced protein synthesis. These negative effects of excess dietary leucine may be overcome by addition of extra valine, isoleucine and tryptophan, which indicates that pigs fed diets based on high quantities of protein from corn or sorghum may have a different amino acid requirement than pigs fed other diets. Nevertheless, the concept for ideal protein has proved to work well under most practical circumstances and is the preferred method for formulating diets in the global swine industry.

Minerals. Of the macro-minerals, calcium, phosphorus, sodium and chloride are routinely added to swine diets. Historically, most of the focus has been on phosphorus because of the high cost of feed phosphates, combined with the risk of pollution of the external environment from phosphorus excreted in the manure. Due to great variability in the digestibility of phosphorus among feed ingredients, diets are usually formulated based on values for the standardized total tract digestibility of phosphorus that have been determined for most feed ingredients. Unlike values for apparent total tract digestibility of phosphorus, values for standardized total tract digestibility are additive in mixed diets and should, therefore, always be used in diet formulation.

Much of the phosphorus in major feed ingredients of plant origin is bound to phytate and is, therefore, poorly digested by pigs, which is the reason there is a need for phosphorus supplementation from feed phosphates such as dicalcium phosphate and monocalcium phosphate. However, the phosphorus bound to phytate may be released by adding microbial phytase to the diet, which increases the digestibility of phosphorus in the diet and, thus, reduces the need for adding feed phosphorus to the diets. This results in a substantial reduction in the amount of phosphorus in manure as well as a reduction in the cost of diets. There are a number of commercial phytase products available, and most often, 500-1,000 units of microbial phytase are needed to maximize the release of phosphorus in the diets. Results from recent research have indicated that greater doses of microbial phytase may have further beneficial effects in addition to the release of phosphorus, so phytase is sometimes added in quantities of 1,500-2,500 units per kilogram of complete feed. However, at this point, there is a need for additional data to document the benefits of "super-dosing" phytase.

The digestibility of phytate phosphorus is also increased if feed ingredients or diets are fermented or soaked in water, so all co-products from the wet milling industry have a greater digestibility of phosphorus than ingredients from the dry milling or dry-grind industries. Feed ingredients that have been fermented, such as fermented soybean meal or DDGS, also have much greater digestibility of phosphorus than conventional soybean meal and corn. Recent research has documented that corn/soybean meal diets that contain microbial phytase and at least 20% DDGS may not need the addition of any feed phosphates because the digestibility of phosphorus in such diets is improved to a level that will meet the phosphorus requirements of the pigs.

The majority of calcium in diets for pigs is provided by calcium phosphates and limestone, whereas plant-based feed ingredients generally contain low amounts of calcium. Unlike the situation for phosphorus, the digestibility of most sources of calcium has not been reported until recently, but it is now recognized that the standardized total tract digestibility of calcium varies among sources of calcium. It has also been demonstrated that the digestibility of calcium is increased by the use of microbial phytase in the diets, which means phytase increases the digestibility of both phosphorus and calcium.

Knowledge about the requirements for digestible calcium by different categories of pigs is limited, but because of the low cost of limestone, the conventional wisdom has been to provide generous amounts of calcium in the diets to make sure pigs are not limited in this mineral. However, oversupplying calcium has detrimental effects on pig growth performance because excess calcium chelates with phosphorus and forms an un-digestible mix in the intestinal tract, thus reducing the absorption of phosphorus. The current recommendation is that the ratio of total calcium to standardized total tract digestible phosphorus should not exceed 2.15:1. If diets for growing and finishing pigs are formulated based on the standardized total tract digestible calcium to standardized total tract digestible phosphorus ratio, this ratio should not exceed 1.35:1. However, further research is required to accurately estimate the digestible calcium requirement for growing pigs.

Six micro-minerals — iron, zinc, manganese, copper, iodine and selenium — are added to all swine diets. Historically, these minerals have been provided using sulfate, oxide or chloride forms, but there is interest in potentially using so-called "chelated" forms of some of these minerals. Chelated minerals are chelated to amino acids, proteins or carbohydrates, and because these chelates are less likely to interact with other minerals in the intestinal tract of pigs, the digestibility of chelated minerals is increased compared with minerals that are not chelated. The cost is greater for chelated versus traditional minerals, but because of the increased digestibility of chelated minerals, it may be possible to reduce the inclusion of the minerals in the diets if chelated forms are used. It is also possible that chelated minerals have other benefits in terms of changing the intestinal microbiota, but conclusive research to demonstrate such effects has not been published.

Vitamins. All four fat-soluble vitamins (A, D, E and K) are usually added as specific supplements to all swine diets. In addition, four B vitamins (riboflavin, niacin, pantothenic acid and B12) are always added to swine diets, and thiamin, folic acid, vitamin B6 and biotin are also often included in diets fed to pigs in confinement. Choline may be added to diets for sows. There is, however, limited information about the exact requirements for each vitamin, and it has not been possible to demonstrate a definite requirement for some vitamins. However, the general trend in the industry is to provide all vitamins in generous quantities that sometimes exceed the estimated requirements by several-fold.

Water. Water is usually provided separately, but an adequate supply of easily available, and safe water is critical for pig health and performance. It is especially important to ensure that nipple waterers deliver an adequate water flow rate.

Nursery pig programs

Ingredients. Nutritional programs for newly weaned pigs are very different from those for older pigs because of the immaturity and rapid development of the digestive and immune systems of the young pigs. While nutrient levels are important in all diets, the focus in designing diets for young pigs is on nutrient sources (ingredients). In fact, the industry uses several special (and expensive) ingredients in diets for nursery pigs that are not used in diets for older pigs. The younger the pig is at weaning, the more important

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these special ingredients are.

Inclusion of spray-dried plasma and a source of lactose is important during the immediate postweaning period. Lactose is usually provided by whey powder or whey permeate. High levels of conventional soybean meal should be avoided in the diets fed during the postweaning period, and animal protein sources such as fish meal, blood meal, blood plasma, blood cells or poultry byproduct meal are, therefore, usually used as sources of indispensable amino acids. However, fermented or enzyme-treated soybean meal is now available in the U.S. These ingredients contain fewer anti-nutritional factors than conventional soybean meal and, as such, can be included in diets for weanling pigs, thus reducing the need for animal proteins.

Phase feeding. Special ingredients become gradually less important as the pig matures after weaning. Special ingredients are expensive, so it is important to use as little of them as possible. For this reason, a three-phase or a four-phase feeding strategy is usually utilized during the postweaning period that uses only a few kilograms per pig of the phase 1 diet, which contains the most expensive ingredients.

Finishing pig programs

Relationship of protein accretion to energy intake. Much of the logic in designing nutritional programs for finishing pigs is derived from the perceived relationship between protein accretion rate and energy intake, as shown in Figure 3. The "M" represents the energy requirement for maintenance. This shows that protein accretion increases as energy intake increases until it reaches a maximum point, and then it plateaus. Evidence indicates that the upslope is linear and that the maximum level of protein accretion occurs when energy intake no longer is limiting for protein accretion. The point at which this occurs is greatly influenced by the genetic background of the pigs. Modern genotypes of pigs have the genetic capacity to deposit protein at very high levels of energy intake, and in commercial settings, the maximum capacity for protein deposition may never be reached because the pig is unable to consume enough energy to meet the requirement for supporting maximum protein accretion. In this situation, the lysine requirement expressed in grams per day changes dramatically as feed intake changes, but the lysine requirement expressed as a percentage of the diet is relatively constant.

Minimum lysine-to-crude protein ratios in feed ingredients that are not heat damaged

Ingredient	Minimum ratio (%)
Soybean meal	6.0
Other soybean proteins	6.0
Corn	3.1
Corn DDGS	3.1
Canola meal	5.2
Sunflower meal	3.4

Energy density. The response to increasing the energy density of the finishing pig diet, usually by adding fat, appears to depend on the environment. Feed efficiency is always improved, and on commercial farms, growth rate usually increases as well. Thus, greater throughput can be obtained if fat is added to the diets, but whether or not this is economical depends on the cost of added fat relative to the cost of corn and soybean meal. The quality of fat also needs to be taken into account. In general, the greater the percentage of fatty acids in the fat and the lower the concentration of free fatty acids and impurities, the greater the energy value. There is also evidence that the energy value of fats containing unsaturated fatty acids may be greater than in fats with saturated fatty acids. The bottom line is that there may be considerable differences in the quality and energy value among sources of fats that are available for use in diets for pigs, and the quality of a specific source of fat should, therefore, always be checked before that source of fat is used.

Amino acids. Using the mathematical model offered by NRC (2012) to estimate the amino acid needs of finishing pigs is recommended. This model uses a factorial approach, estimating separate daily requirements for maintenance and protein accretion and calculating the amount of each amino acid needed to support the level of performance of pigs specified by the user. The model first estimates the requirement for lysine and then uses ratios to estimate the requirements for the other indispensable amino acids as explained above for the concept of ideal protein.

The estimation of maintenance requirements considers two distinct components: (1) endogenous intestinal losses — the larger component — considered to be linearly related to feed intake, and (2) skin and hair losses, which are related to bodyweight. The lysine requirement for protein accretion starts with the assumption that the accreted protein contains 7.1% lysine. The efficiency with which absorbed lysine is used for protein accretion is assumed to decline as the pig grows, such that the amount of lysine needed to support 100 g of protein accretion is 10.4 g in a 20 kg pig and 12.5 g in a 120 kg pig. Adjustments for the greater efficiency of pigs with faster protein accretion is incorporated into the model.

As mentioned before, using the requirement for lysine to calculate the requirement for all other indispensable amino acids is an accepted and widespread practice that has proved to result in satisfactory pig growth performance. The requirement for digestible lysine is relatively well characterized for most genotypes of pigs, which is a prerequisite for using this approach. However, all processed feed ingredients to which heat has been applied may have been heat damaged, and the amino acid with greatest risk of heat damage is lysine. Heat damage results in a reduction in the concentration as well as the digestibility of lysine, and because of heat damage, there is greater variability in the concentration and digestibility of lysine than for any other amino acid among different batches of the same feed ingredient. To be certain that pigs receive the intended levels of digestible lysine, it is necessary to have quality control measures in place to make sure each batch of each feed ingredient is not heat damaged. Because of the reduction in lysine concentration in heat-damaged feed ingredients, and because crude protein is not changed by heat damage, calculating the lysine-to-crude protein ratio will provide an indication about whether or not a feed ingredient has been heat damaged. The lysine-to-crude protein ratio in feed ingredients that have not been heat damaged has been determined for some of the most commonly used feed ingredients fed to pigs (Table). If the ratio between lysine and crude protein is less than the values indicated in the Table, the ingredient is most likely heat damaged. If a heat-damaged ingredient is received, supplemental crystalline lysine will be needed to maintain satisfactory animal growth performance.

Phase feeding. Amino acid requirements expressed as a percentage of the diet decline during the feeding period for finishing pigs, so providing appropriate diets requires frequent diet changes. Feeding too few diets causes significant overfeeding of amino acids during some periods of the growing phase, with detrimental effects on both cost and the nitrogen content of manure. The most satisfactory method for managing those changes is to provide a predetermined amount of each feed (a feed budget). Most commercial systems use 6-10 different diets from weaning to market. Feeding gilts and barrows separately, if practical, also provides an opportunity to optimize amino acid provisions, because gilts have a greater requirement for amino acids — measured as a percentage of the diet — than barrows.

Gestating sow programs

Amino acids. The amino acid requirements of gestating sows are relatively low because most of the energy is used for maintenance, and the amino acid requirements for maintenance are low relative to the energy requirement. However, younger sows are still growing and need amino acids for body protein deposition, and older sows may have lost body protein during lactation that needs to be replenished. So, the requirements for amino acids in gestating sows are a combination of requirements for maintenance and protein deposition.

Energy. Gestating sows differ from pigs in most other stages of production in needing a feed intake restriction. That creates challenges in the physical management of feed delivery to ensure that each animal consumes the target amount of feed. Sows that consume too little during gestation enter the lactation phase in a condition with limited body stores of fat and protein. Sows that consume too much during gestation eat too little during lactation, when adequate energy intake is most critical.

The fact that the energy requirement of gestating sows is less than their voluntary intake allows for the use of fibrous ingredients in the diet without reducing performance, and it is also believed that dietary fiber contributes to increased satiety of sows. It is, therefore, common to add at least one high-fiber ingredient in diets for gestating sows.

Historically, sows were kept on a low plane of nutrition early in gestation, and the provision of feed was increased during the last three to four weeks of gestation to account for the increased nutrient demand of the fetuses during this period. However, it has been demonstrated that by feeding approximately 2.5 times the energy requirement during early gestation, pig litter size increases. In contrast, there appears to be no benefit of increasing feed allowance during late gestation, so sows may be fed the same amount of feed during late gestation as during the middle of gestation.

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Lactating sow programs

High intake needed. Modern sows can produce impressive quantities of milk, and it requires large amounts of energy, amino acids and other nutrients to support that milk production. That's why it is important that sows consume enough feed to supply those nutrients. Inadequate nutrient intake can reduce milk production and/or cause mobilization of excessive amounts of maternal body tissue. It can also create metabolic/endocrine conditions that reduce the quality of the developing ovarian follicles that will produce the next litter of piglets.

It is both very important and very difficult for lactating sows to achieve adequate feed intake. However, feed intake can be encouraged through proper management. Heat stress should be minimized by taking appropriate environmental management steps, such as drip cooling. The feeding process should be managed to encourage a high level of feed intake. Adequate provision of water is necessary to encourage maximum feed intake and milk production.

Fat. Supplementing lactation diets with fat is unlikely to improve subsequent reproduction in most cases, but it almost always increases litter weaning weights and may be recommended for that reason. This is an effect of dietary fat resulting in increased milk fat concentrations and, therefore, increased energy intake of the nursing piglets.

Amino acids. The amino acid requirements of lactating sows can be estimated by a factorial approach, as described previously for finishing pigs; the model is available from NRC (2012). The factors to be considered are maintenance, the requirements of the mammary gland for milk production and the amino acids contributed by mobilization of maternal tissue. Again, the requirements for amino acids other than lysine are estimated using ratios.

Summary

The science and practice of swine nutrition are old but very active and increasingly sophisticated. This article provides an overview of salient aspects of swine nutrition, with some expansion in especially critical or rapidly changing areas. ■