Nutrition & Health: Swine

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THE purpose of this paper is to provide a brief overview of salient aspects of swine nutrition. We recommend that the reader who wants more detailed information consult a more thorough treatment of the subject, such as Lewis and Southern, 2000 (Swine Nutrition, 2nd ed.).

The National Research Council (1998) provides estimates of nutrient requirements for all phases of pig production. It is important to remember that these estimates do not contain safety factors to allow for variation in pig requirements, variation in level or availability of nutrients or loss of vitamin potency during processing and storage, so it is normal to feed higher levels of some nutrients, especially vitamins and trace minerals.

Overview of nutritional needs

The pig requires energy, amino acids, minerals and vitamins from its diet plus water, which is usually provided separately. Several other items may also be included in the diet for purposes other than to meet the nutritional needs of the animals, but they will not be considered in this section.

Energy. Energy is perhaps the most basic of the nutritional needs, as it is needed to drive all productive functions of the body. Fats, carbohydrates and proteins all contribute energy to the body, but they vary in energy density and in the efficiency with which that energy is used.

An energy system expresses the energy needs 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 has advantages and disadvantages.

The total amount of energy in feedstuffs (the amount liberated by burning) is the gross energy (GE), but the animal cannot use all of it. Some of the energy-containing nutrients are not digested and absorbed from the digestive tract and are excreted in feces, and the amount of fecal energy varies enormously among feedstuffs. Subtraction of fecal energy gives DE. Actually, some of the fecal energy is not in undigested dietary components but comes from the body (is endogenous), so what we measure is technically apparent DE in contrast to the theoretical true DE that would account for endogenous energy. DE is a useful and widely used energy system.

Some energy is also excreted in urine, and some is lost as methane gas from the digestive tract. Subtraction of these losses from DE produces ME. Energy lost in methane is small and is usually not measured. Energy lost in urine is associated with nitrogen excretion, so it is closely related to the protein level and amino acid balance of the entire diet. The ME:DE ratio is quite constant across feedstuffs, with a small systematic variation associated with protein concentration. There is, therefore, little advantage in using ME rather than DE as an energy system for pigs. In fact, ME values are less reliably additive because of their sensitivity to total dietary amino acid balance, so many prefer DE to ME as a practical energy system.

Unfortunately, DE and ME share serious defects, because they are unable to reflect the widely different metabolic efficiencies of use of different energy substrates by the body. The heat increment (metabolic inefficiency of use) of protein is high, so DE and ME systematically overvalue high-protein feedstuffs. The heat increment of fiber is also high due to inefficiencies in both fermentation in the digestive tract and the use of the resulting short-chain fatty acids in the tissues, so DE and ME also overvalue fibrous feedstuffs. The heat increment of dietary fat is low, especially when it is deposited in the body or in milk, so DE and ME undervalue fats. These errors are non-trivial — large enough to be practically important.

An NE system corrects a substantial part of these systematic errors. The magnitude of the errors is indicated by the variation in NE:ME in the examples in Table 1, based on published values. NE is theoretically much more accurate in matching energy needs and energy supply than are DE and ME, but accurate NE values are substantially more difficult and expensive to generate experimentally. The key practical question facing nutritionists is whether the available NE values are accurate enough to gain theoretical advantages from using NE over DE or ME. Recent data support the concern about currently available NE values but suggest they are superior to ME in most cases.

The efficiency of using dietary energy depends not only on the diet composition but also on the use to which the animal puts the energy (e.g., protein versus fat accretion). Therefore, the ultimate energy system will go beyond NE to consider animal factors as well.

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 must be measured to the end of the small intestine (ileum) because the microbes in the hindgut degrade and/or synthesize amino acids, largely without making them available for use by the host animal's tissues.

Measures of apparent digestibility always show low values for a few key amino acids (threonine, tryptophan, cysteine) because they are in high concentrations in endogenous proteins. We recommend the use of standardized digestibility values, derived using a protein-free diet to provide an estimate of endogenous losses. Many values labeled true digestibility are more correctly identified as standardized digestibility.

The pig requires an adequate dietary supply of each of the 10 essential (indispensable) amino acids. Independent estimation of requirements for each of the 10 under varying conditions is a daunting task, especially considering the limited resources for research. Therefore, nutritionists have developed a short-cut method for estimating requirements for all 10, using the concept of ideal amino acid ratios. First, we measure the requirement for lysine under the conditions of interest. Then we estimate the corresponding requirement for each of the other nine expressed as a ratio to the requirement for lysine. These ratios are quite different for maintenance than for protein accretion, so we prefer to use both sets of ratios in a factorial approach to estimation of requirements.

The ratios estimated by NRC (1998) are shown in Table 2. Note that some ratios would be different if using apparent digestibility. There is currently a great deal of research activity directed to improving the values reported in Table 2.

Minerals. Of the macro-minerals, calcium, phosphorus, sodium and chloride are routinely added to swine diets. Most recent interest has been in phosphorus because of the entry into the market of phytase enzymes.

Much of the phosphorus in major feed ingredients of plant origin occurs in the form of phytate, a compound that is poorly digested in the nonruminant digestive tract. The poor bioavailability of phytate phosphorus creates a need for phosphorus supplementation from expensive mineral ingredients. Phytase enzyme products added to the feed increase the bioavailability of phytate phosphorus, thus reducing the need for phosphorus supplements. The most important benefit is a substantial reduction in the amount of phosphorus in manure.

Six micro-minerals (iron, zinc, manganese, copper, iodine and selenium) are added to all swine diets, and another (chromium) is often added to sow diets. Of special current interest is whether organic forms of these minerals are superior to the inorganic forms. Chromium must be provided in an organic form, and there is growing evidence of the value of selenium in the form of selenomethionine.

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 usually added to all swine diets. Sow diets are usually supplemented with rather high levels of three additional vitamins (choline, biotin and folic acid). Nursery pig diets often contain supplements of vitamin B6, choline, biotin and a stabilized form of vitamin C, and some nutritionists add choline to finishing pig diets.

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.

Nutritional programs: Finishing pigs

Relationship of protein accretion to energy intake. Much of our logic in designing nutritional programs for finishing pigs derives from the perceived relationship of protein accretion rate to energy intake (Figure). The "M" represents the energy requirement for maintenance. This Figure shows that protein accretion increases as energy intake increases until it reaches a maximum point, and then plateaus. The evidence indicates that the upslope is linear. The maximum level of protein accretion occurs when energy intake no longer limits it. The limitation then is some other factor, such as amino acid supply or a nebulous "genetic limit." If protein accretion becomes limited by amino acid supply, and that limitation is released by providing a higher level of that amino acid, then the upslope can extend to higher levels of protein accretion and energy intake.

The slope of the ascending line in the Figure indicates the proportion of incremental energy used to drive protein accretion, and therefore the leanness of the animal.

Sometimes, especially in young pigs, the graph in the Figure shows only the linear upslope and no plateau, suggesting that the pig is unable to consume enough energy to exceed its requirement to support 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. As the pig grows, its intake increases relative to the breakpoint and may reach the plateau. In this situation, the lysine requirement expressed in grams per day is relatively constant, but the lysine requirement as a percentage of the diet varies. Voluntary feed intake of pigs in commercial production is usually notably less than that of pigs in research farms, so pigs on commercial farms may spend more of their time in the energy-limiting (no plateau) stage of growth.

Energy density. The response to increasing the energy density of the diet of finishing pigs, usually by adding fat, appears to depend on the environment. Feed efficiency is always improved. Growth rate stays constant or increases slightly in most research-farm studies, but increases markedly in commercial-farm experiments. The difference should be expected from the lower feed intake on commercial farms,

1. Energy values (kcal/kg) of selected ingredients

Ingredient	DE	ME	NE	NE:ME
Corn	3,525	3,420	2,395	0.70
Sorghum	3,380	3,340	2,255	0.68
Soybean meal	3,685	3,380	2,020	0.60
Canola meal	2,885	2,640	1,610	0.61
Wheat midds	3,075	3,025	1,560	0.52
Alfalfa meal, dehy., 17% CP	1,830	1,650	910	0.55

2. Ideal ratios of amino acids to lysine[1]

Amino acid	Maintenance	Protein accretion	Milk synthesis	Body tissue
Lysine	100	100	100	100
Arginine	-200	48	66	105
Histidine	32	32	40	45
Isoleucine	75	54	55	50
Leucine	70	102	115	109
Methionine	28	27	26	27
Methionine + cysteine	123	55	45	45
Phenylalanine	50	60	55	60
Phenylalanine + tyrosine	121	93	112	103
Threonine	151	60	58	58
Tryptophan	26	18	18	10
Valine	67	68	85	69

[1]Source: Nutrient Requirements of Swine: 10th Revised Edition (1998).

leaving those pigs on the ascending slope of the Figure. Energy densities greater than those of a corn-soy diet are usually beneficial in diets for finishing pigs on commercial farms.

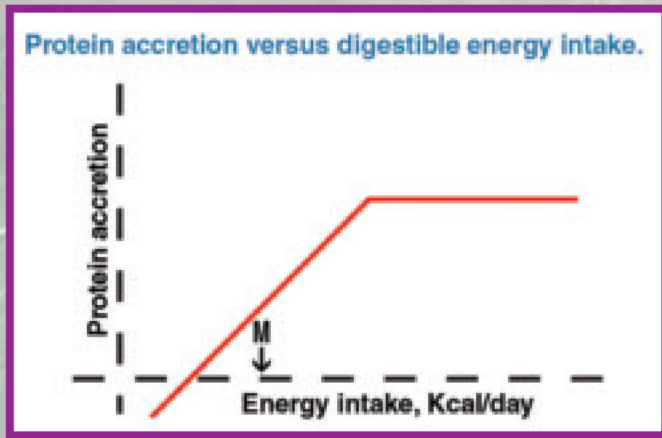
Amino acids. We recommend using the mathematical model offered by NRC (1998) to estimate amino acid needs of finishing pigs. This model uses a factorial approach, estimating separate daily requirements for maintenance and protein accretion. It estimates the amount of each amino acid needed to support the level of performance of pigs in a given situation, but has no way to determine whether higher amino acid levels might increase the performance. It first estimates the requirement for lysine, then uses ratios (Table 2) to estimate the requirements for the other essential amino acids.

The maintenance requirement is taken from empirical data, and is 0.036 g/(kg bodyweight)$^{0.75}$ in the case of lysine. The lysine requirement to support each gram of protein accretion is taken to be 0.12 g from a review of pertinent data. Then the challenge is to estimate the protein accretion rate of pigs at a given time and under a given set of conditions. Key to this estimate is the close relationship between body protein content and carcass fat-free lean content (2.55 g carcass fat-free lean/g protein), so the challenge is to estimate the daily fat-free carcass lean accretion.

There are two methods for estimation of daily carcass fat-free lean accretion. The simpler one is to estimate total carcass fat-free lean accretion for the entire feeding period and divide by the number of days on feed to get the mean daily accretion rate. That value can be converted to an accretion rate for each day on feed, using an equation in the model that describes the shape of a typical accretion curve over time. The total carcass fat-free lean accretion for the entire feeding period can be obtained by subtracting the lean content of the pig at the beginning of the feeding period (taken as a proportion of bodyweight) from the content at slaughter. The content at slaughter is the product of the hot carcass weight and the percent fat-free lean in the carcass. Note that many slaughter plants provide a different leanness value than this one.

The second method for estimation of daily fat-free lean accretion relies on serial ultrasound measurements of a sample of pigs throughout the feeding period. The fat-free carcass lean content (and thus the body protein content) can be estimated on each of the measurement days from the ultrasound data, and mathematical procedures can convert those values to a protein accretion curve over time.

The steps outlined above will produce an estimate of the daily lysine requirement for pigs under the target conditions at each stage of growth. Requirements for the other essential amino acids are estimated from the lysine values using the ratios in Table 2.



Then, it is necessary to convert the daily requirements to percent of the diet, which requires data on daily feed intake at each growth stage. It is imperative that the feed intake values be measured under the same conditions. The model contains a default feed intake equation, but it should be used only as a last resort.

Remember that the model provides estimates of the amount of amino acids needed to support the measured level of growth performance. If these estimates are less than currently fed, they are reliable. However, if they are similar to the levels currently fed, these levels may be restricting growth. In that case, it is appropriate to increase amino acid levels and measure the resulting performance to determine whether it is increased.

Phase-feeding. Amino acid requirements expressed as percent of the diet decline substantially during the feeding period for finishing pigs, so feeding appropriate diets requires frequent diet changes. Feeding too few diets causes significant overfeeding of amino acids, with detrimental effects on both cost and the nitrogen content of manure. The most satisfactory method for managing those changes is provision of a predetermined amount of each feed (a feed budget).

Nutritional programs: Gestating sows

Energy. Gestating sows differ from pigs in most other stages of production in needing a restriction of feed intake. That creates substantial 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 challenging lactation phase in a precarious condition with limited body stores of fat and protein to draw upon. 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 the use of fibrous ingredients in the diet, without reducing performance.

Amino acids. The amino acid requirements of gestating sows are relatively low during most of gestation because most of the energy is used for maintenance and the amino acid requirements for maintenance are low relative to the energy requirement. Requirements for both energy and amino acids increase markedly in late gestation.

Nutritional programs: Lactating sows

High intake needed. Modern sows can produce impressive quantities of milk, and that requires large amounts of energy, amino acids and other nutrients to support that milk production. It is, therefore, important that sows consume enough feed to supply those nutrients. Inadequacy of 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.

Achievement of adequate feed intake by lactating sows is both very important and very difficult. However, feed intake can be encouraged by appropriate management. Heat stress should be minimized by appropriate environmental management steps, such as drip-cooling. The feeding process should be managed to encourage a high level of feed intake.

Fat. Supplementation of 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 appears to be a specific physiological effect of dietary fat, not of energy density.

Amino acids. The amino acid requirements of lactating sows can be estimated by a factorial approach, as described above for finishing pigs. The factors to be considered are maintenance, 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 (Table 2). The lysine requirement for maintenance is the same in relation to bodyweight as for finishing pigs. The requirement for the mammary gland is estimated to be 22 g apparent digestible lysine/kg litter growth.

Recent research from our laboratory indicates that the NRC (1998) estimate of the valine:lysine requirement ratio for milk production is too high. Correction of that ratio downward will allow use of more crystalline amino acids.

Nutritional programs: Nursery pigs

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, we use several special (and expensive) ingredients in diets for nursery pigs that we do not use in diets for older pigs. The younger the pig is at weaning, the more important are these special ingredients.

Specific ingredients appear important in the diet of newly weaned pigs, although we do not clearly understand their physiological mechanisms. They include spray-dried plasma, milk products and a small amount of fish meal. High levels of soybean meal should be avoided. Other ingredients can supply the bioavailable amino acids needed, including pet food-grade poultry meal, further-processed soy products, spray-dried blood meal, spray-dried blood cells, dried porcine solubles, higher levels of fish meal and crystalline amino acids.

Phase feeding. The special ingredients become gradually less important as the pig matures after weaning. They are expensive, so it is important to use as little of them as necessary. Therefore, we use a small amount (perhaps only a pound per pig) of an expensive diet containing high levels of these ingredients immediately after weaning, then move promptly through a series of diets with declining cost and declining levels of special ingredients, using a feed budget. Note that phase feeding for nursery pigs changes primarily nutrient sources, while phase feeding for finishing pigs changes nutrient levels. Both are designed to control costs.

Diet and health

There is growing awareness that certain dietary ingredients may improve health of pigs, especially improving resistance to enteric infection. For several decades, we have added antimicrobials to swine feeds to improve productive performance and health. We continue to do so, but there are valid reasons for minimizing our use of antimicrobials. Few other ingredients will be as powerful as antimicrobials, but we have reason to be optimistic that several may be useful. In fact, we already use spray-dried plasma, milk products and high levels of zinc and copper to improve health of young pigs. Other strong candidates include mannan oligosaccharides, organic acids, egg products, direct-fed microbials (bacteria), yeasts and yeast products, botanical products, clays and others.

Summary

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

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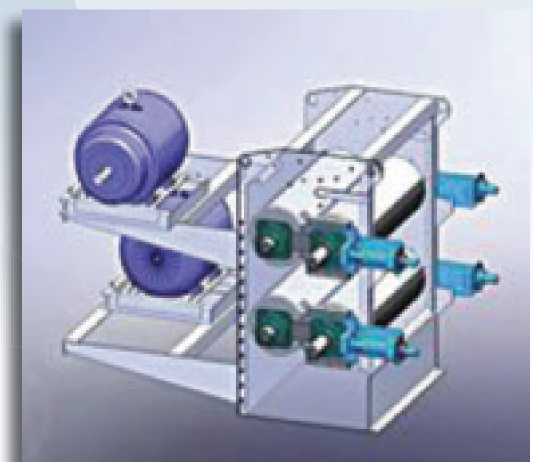

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