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Rendered Feeds in Swine feeding

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Introduction

The protein-rich feeds and energy dense fats produced by the rendering industry have been, and will continue to be, an integral part of profitable swine feeding programs. Tankage and meat meal were once thought to be essential dietary ingredients for maximum performance of pigs not raised on pasture. This "animal protein factor" was later determined to be vitamin B_{12}. Nutritionally adequate swine diets can now be made without use of feeds from the rendering industry due to commercial availability of vitamin B_{12} and mineral supplements. However, the rendered feeds and fats will continue to be used in swine diets due to their nutrient profile in relation to cost.

The criteria for selecting a feedstuff for use in swine diets include: (1) nutrient content in relation to nutrient needs, (2) biological availability of the nutrients, (3) variability in content of nutrients and physical traits among samples of the same feedstuff (4) growth promotion not explained by nutrient content, (5) palatability, (6) physical traits that affect milling and mixing (such as density and viscosity) and (7) presence of toxins or pathogens. This chapter will primarily address the first five points and provide usage recommendations for the rendered feeds and fats.

Fundamentals of swine nutrition and feeding. A brief review of the fundamentals of swine nutrition and feeding will help the novice reader to better understand the later discussion of the use of rendered feeds in swine diets.

There are over forty individual nutrients required in the pig diet. Fortunately, many nutrients are either present in adequate amounts in the normal feedstuffs fed or can be easily and economically supplemented from synthetic sources. The nutrients of economical concern in commercial swine diets are energy, protein (amino acids), calcium and phosphorus. Over 95% of the cost of feeding swine lies in meeting the needs of these nutrients.

Energy. Energy is measured as either digestible energy (DE), metabolizable energy (ME) or net energy (NE). Each method attempts to quantify the amount of energy a feedstuff can supply by subtracting from the feed's gross (total) energy (GE) the energy that is lost in the waste products resulting from the digestion and utilization of the feedstuff. DE equals, GE minus fecal energy; ME equals DE minus the energy in urine and gases of fermentation; NE equals ME minus the heat increment. Heat increment is the energy expended by the pig to digest and utilize the feedstuffs, and varies greatly among feedstuffs, being the lowest for the fats and oils, and highest for the fiber rich grain by-products.

Swine diets are based on the cereal grains due to their high energy content. Pigs completely digest the starch present in the grain. Fiber-rich feeds have low DE and ME because pigs cannot efficiently digest fiber; bacterial fermentation in the digestive tract, which is required to break down the components of fiber, is limited to the large intestine. Heat increment for the high-fiber feeds is also high due to the inefficiencies of fermentative digestion and the utilization of energy yielding metabolites from fermentation. Fats and oils, on the other hand, have the highest DE, ME and NE due to their high GE, high efficiency of digestion and absorption, and low heat increment. On an equal weight basis, fats and oils will provide over twice the energy found in cereals.

Energy density affects voluntary feed intake of swine. As energy density of the diet increases, daily intake decreases so that daily energy intake remains about the same. Adding animal fat to diets of growing pigs increases energy density, lowers feed intake and typically improves feed efficiency. Because a reduction in feed intake lowers intake of all nutrients, concentration of nutrients in the diet should increase proportional to dietary energy. Nutrient requirements of pigs are often expressed in relation to energy density. Protein/calorie and lysine/calorie ratios are primarily important.

Protein. Protein is made up of 22 different amino acids. The pig lacks the metabolic pathways to synthesize nine amino acids from other precursor molecules. These are the "dietary essential amino acids" and are the real nutrients needed by the pig, not protein as such.

Protein is the primary constituent of muscles, enzymes and some hormones. Because dietary amino acids are used to synthesize protein in the body, a deficiency of any one of the essential amino acids will limit protein synthesis and severely impact growth rate, feed efficiency, and carcass merit of growing-finishing pigs and reproductive performance in the sow.

The proportion of the nine essential amino acids in the average protein synthesized by the pig is called the "ideal protein" pattern (Table 1). By convention, the ratios of the amino acids are expressed in relation to lysine. Examination of the ideal pattern indicates that pigs need relatively large amounts of some amino acids (lysine, leucine, phenylalanine + tyrosine) and only small amounts of others (tryptophan).

The proportion of an amino acid in a feed that is absorbed from the digestive tract is called true digestibility. True digestibility is difficult, if not impossible, to determine, because of the endogenous amino acids in feces or ileal digesta from sloughed cells and secretions of the digestive tract. Apparent digestibility does not account for these endogenous losses, and as such is a flawed measure of amino acid absorption. On a practical basis, however, apparent digestibility is likely the best measure due to the difficulty of measuring endogenous secretions, and the fact that endogenous losses are affected by the physical and chemical characteristics of a feedstuff.

Apparent digestibilities of amino acids determined at the end of the small intestine are more accurate than apparent digestibilities determined over the total digestive tract. Amino acids are not absorbed from the large intestine, and the microflora in the large intestine degrade and synthesize amino acids. Digestibilities determined at the end of the small intestine are called "ileal" digestibilities, since the end segment of the small intestine is the ileum.

Protein quality refers to the ability of a feedstuff or diet to provide the dietary essential amino acids needed by the pig. Protein quality can be reduced by either a deficiency of one or more dietary essential amino acid, or by an excess of essential amino acids. The protein in cereal grains is low quality because of multiple amino acid deficiencies. Compared to the needs of a 100 lb high-lean genotype pig corn, for example, is deficient in lysine, tryptophan, threonine, isoleucine and methionine + cystine. Lysine is the "first limiting amino acid" in corn, and all cereals grains, because the deficiency is the greatest.

High-protein feedstuffs such as the rendered meals and oilseed meals are used to balance the amino acid deficiencies of the grains. A good quality protein feedstuff balances the amino acid deficiencies of the cereal grain while minimizing dietary protein. The latter point is important because excess dietary essential amino acids in the excess protein may reduce pig performance. Feeding excess protein usually increases diet cost.

Diets based on corn and using either the rendered high-protein feeds, or common oilseed meals were formulated to meet the digestible amino acid needs of a 100 lb high lean genotype pig (.72% digestible lysine, digestible contents of other amino acids based on ratios to lysine in the ideal protein). Protein contents of the diets, and the first-limiting amino acid in each diet are: soybean meal, 17.8%, lysine; Menhaden fish meal, 22.2%, tryptophan; poultry-by-product meal, 23.7%, tryptophan; peanut meal 28.2%, lysine; cottonseed meal, 29.8%, lysine; meat and bone meal

45.1%, tryptophan; spray dried blood meal, 48.4%, isoleucine; feather meal, 83.7%, lysine. Because of the low content of lysine, tryptophan and isoleucine, the rendered high-protein feeds are best used to supplement a diet containing cereals and soybean meal rather than be the sole source of supplemental protein in a cereal-based diet.

The poor protein quality of the rendered feeds can be improved by the use of feed-grade lysine and tryptophan to balance the deficiencies of the feeds. By using these two amino acids, the protein content of diets formulated as described above are: menhaden fish meal 16.3%, poultry-by-product, 17.1%; meat and bone meal, 21.2%; feather meal 20.2% .

Macrominerals. Of the six macrominerals, calcium, phosphorus, sodium and choline are likely to be deficient in practical diets unless supplemental sources are added. Sodium and choline needs are easily met by adding salt. The cereals are almost devoid of calcium and are low in phosphorus; a dietary deficiency of both minerals will result unless the diet contains supplemental calcium and phosphorus from either the protein feeds or inorganic sources. A deficiency of either calcium or phosphorus or an imbalance of calcium and phosphorus will result in lowered performance (reduced growth, milk production) followed by abnormalities of the bone due to poor mineralization, ricketts in growing pigs and spontaneous bone fractures in sows. Providing supplemental calcium is inexpensive and easy to do due to the abundance and low cost of ground limestone. Phosphorus supplementation, on the other hand, is expensive.

Feedstuffs vary greatly in their ability to provide phosphorus to pigs, due to differences in total content and to differences in biological availability of phosphorus. "Availability" refers to the proportion of the mineral from a feedstuff that is actually utilized and deposited in the bone. Thus availability includes both the effects of digestion and utilization after absorption. Measures of bone strength and bone ash are the criteria used to determine availability. For phosphorus, monosodium phosphate, a high quality inorganic source of phosphorus, serves as a reference point and assigned a relative avaliability of 100. For example, the availability of phosphorus in corn is estimated to of 15%, compared to a value of 100% for monosodium phosphate.

Phosphorus in the rendered high-protein feeds containing bone is much more available to the pig than phosphorus from cereals and the oilseed meals. In the latter case, phosphorus is part of phytin in the seeds and is poorly digested. Availabilities of phosphorus, published by the NRC (1988) are: meat and bone meal, 93%; fish meal, 100%; soybean meal, 32% to 35%; cottonseed meal, 21%; corn, 15%; sorghum, 22%. Although the availability of phosphorus in poultry-by-product meal and blood meal have not been reported, their availabilities are likely high. A major nutritional advantage of meat and bone meal, meat meal, fish meal, and poultry-by-product meal is their high available phosphorus content.

Vitamins and Trace Minerals. The pig has a dietary need for 13 vitamins and six trace minerals. The high protein feeds containing meat are excellent sources of vitamin B12, niacin, riboflavin, thiamine, iron, manganese, selenium, and zinc. In the early days of swine feeding, blending of several high-protein feeds with grains and legume products was necessary to meet the vitamin and trace mineral needs of pigs. Today that is not necessary due to use of premixes containing synthetic vitamins and inorganic sources of the trace elements. On an applied basis, vitamin and/or trace mineral content of a feedstuff has little bearing on its economic value due to low cost of vitamin and trace mineral supplementation.

High-Protein Feedstuffs

Content and Availability of Nutrients

An accurate knowledge of the content and biological availability of nutrients to the pig is essential for the proper and economical use of the rendered feedstuffs. Knowing the variability in content of a nutrient among samples of the same feedstuff is also essential for those wishing to ensure a minimum level of a dietary nutrient.

Tables 2 to 11 summarize the protein, calcium, phosphorus, crude fat, and essential amino acid content of the rendered, high-protein feeds. Data for this summary are the result of a survey sponsored by the Fats and Proteins Research Foundation to obtain current nutrient content and availability data for the rendered feedstuffs. Data consist of replies from six large feed manufacturers or renderers, and 42 university reports published after 1985. Table 12 lists DE and ME contents of the high-protein rendered feeds published by the NRC (198). Energy contents were not found for these feeds in the United States and Canadian literature.

Meat and Bone Meal and Meat Meal. Data from meat and bone meal and meat meal reported by commercial sources were segregated into those meals containing at least 4.4% phosphorus, meat and bone meal, and those meals with less than 4.4% phosphorus, meat meal (Table 2). Both meals remain excellent sources of calcium, phosphorus, protein, and amino acids. The meat meals were about 3 percentage units high in protein, .20 percentage units higher in lysine, but 2.3 and 1.2 percentage units lower in calcium and phosphorus, respectively. Both types of meals contained 10.7% fat. Meat and bone meal and meat meal would be considered moderate sources of energy (Table 3). Energy from the fat helps to balance out the lack of energy in the ash content of the meals (26% ash found for 35 samples of meat and bone meal).

As crude protein increases in the meals, amino acid content also increases, but the relationship is not perfect. Table 3 shows the results of regressing amino acid content on protein content of meat and bone meal and meat meal. A perfect correlation of protein and amino acid content would have a correlation coefficient (r) of 1.0. The coefficients for the essential amino acids ranged from .57 for threonine to .78 for threonine; lysine had an r value of .69, and tryptophan had an r value of .57 (Figure 1).

Meat and bone meal and meat meal tend to be variable in nutrient content both among samples produced at the same rendering plant and among different processing plants. The standard deviations (SD) for crude protein content were 3.0 for 426 samples, 4.3 for 71 samples and 1.8 for 676 samples. An example of the variability among processing plants is shown in Table 4. The relatively large processor-to-processor variation suggest feed formulators may be well served to modify nutrient contents based on the origin of the meat and bone meal and meat meal.

Meat and bone meal and meat meal have moderate apparent ileal amino acid digestibilities (Table 5) compared to more digestible feeds such as soybean meal or fish meal. A large variation in amino acid digestibilities also existed among samples of meat and bone meal and meat meal. The mean ± SD values for lysine, tryptophan and threonine are 71 ± 7, 57 ± 9, and 64 ± 6. The cause of this variability is undoubtedly linked to method of determining digestibilities, type of beginning material (soft tissue vs bones) and degree of heat treatment during processing. All rendered products must be heated sufficiently to dry and sterilize the material. Any heat applied beyond this has the potential to lower amino acid digestibility, especially lysine with its free amino group. It should be noted that some meat and bone meals are as digestible as soybean meal (Knabe, 1989).

Dried Blood Products. The dried blood meals, in contrast to the meat and bone meals, were relatively uniform in nutrient content and digestibility (Table 6). Mean protein contents for spray dried blood meals were 88.3% (n = 11), and 89.3% ±2.9 % (n = 97 samples); mean protein contents for ring dried blood meal were 87.6% (n = 7) and 89.6 ± 3.2% (n = 16). Because the number of amino acid analyses for the blood meals was limited (n = 11 or 7 for spray dried and ring dried blood meals, respectively), data for spray dried and ring dried meals were combined. On average, the blood meals contained 8.24 ± .55% lysine, 1.22 ± .30% tryptophan, and 3.93 ± .50% threonine.

Digestibilities of protein and amino acids are uniformly high for both spray dried (n=6) and ring dried (n = 3) blood meals. Lysine digestibilities were 95 ± 2 and 93 ± 1.5 for spray dried and ring dried meals. Of the major protein feeds fed to pigs, only dried skim milk and casein have been found to be as digestible as properly processed blood meals.

Spray dried porcine plasma has an amino acid profile which is distinctly different from that of blood meal, as would be expected, and its apparent digestibility is lower than that of spray dried blood meal (Table 7). Reasons for this lowered digestibility are not evident.

Poultry-By-Product Meal and Hydrolyzed Feather Meal. Data for the poultry-by-product meals are derived primarily from university reports. Amino acid data were not reported by feed manufacturers. Variability in nutrient content among samples was similar to that found for meat and bone meals. Apparent ileal digestibilities, however, were higher than those found for meat and bone meal, and are similar to those reported for soybean meal and fish meal. It should be pointed out that samples evaluated for amino acid digestibility were largely free of feathers.

Nutrient contents for feather meals (Table 9) are also derived primarily from university reports, although one feed manufacturer reported 85.7±1.6% as the protein content for 31 feather meal samples. Digestibility data is limited to only one sample; lysine was poorly digested in that sample.

Menhaden Fish Meal. Data for menhaden fish meal were divided into "normal" and "select" meals based on the description provided by the feed manufacturer or the fish meal producer. One set of data for normal fish mealwas provided as the mean±SD for 24 samples, and as such, could not be combined with data for individual samples. Thus Table 10 shows two nutrient profiles for normal fish meal. The select fish meal data set was from one feed manufacturer. In general, nutrient contents in all three columns agree. The simple weighted mean for calcium, phosphorus, protein, lysine, tryptophan, and threonine are: 5.21, 3.04, 62.3, 4.75, .53, and 2.63%, respectively.

Apparent ileal digestibilities of protein and amino acids for seven samples of menhaden fish meal are shown in Table 11. Due to limited sample numbers, it was not possible to segregate out normal and select meals. Digestibilities were higher than those found for meat and bone meal and similar to those for poultry-by-product meal. Variability was large also, reflecting possible differences in processing method and storage of fish prior to processing.

Use of High-Protein Rendered Feeds in Swine Diets

Meat and Bone Meal and Meat Meal. Meat and bone meal and meat meal are the predominant rendered feedstuff fed to swine. As indicated earlier, both are excellent sources of available phosphorus and calcium and are moderate sources of digestible amino acids and digestible energy.

Use of these meals as the only source of supplemental protein in cereal based swine diets has resulted in inferior performance (Kennedy et al., 1974; Stockland et al., 1970; Peo and Hudman, 1962). Increasing dietary levels of meat and bone meal in diets of growing-finishing pigs (Peo and Hudman, 1962) and weaning pigs (Puchal et al., 1962; Evans and Leibholz, 1979 ab) has resulted in linear depression in performance. Results such as these, linked with the variability in nutrient content among meat and bone meals, has resulted in recommendations for low usage rates of the meals in swine diets. These recommendations are no longer valid due to a better understanding of amino acid requirements and the production of feed grade amino acids.

Low digestible tryptophan content is the primary nutritional factor limiting the use of these meals in diets of growing-finishing pigs, sows and boars. Collagen protein is devoid of tryptophan and may make up 50 to 65% of all protein in meat and bone meals due to its high content in bone protein, connective tissue, tendons, and cartilage (Eastoe and Long, 1960). The reduced digestibility of tryptophan, and other amino acids, is due in part to heat treatment during processing. Increasing heat treatment during processing of meat and bone meals has been shown to lower digestibility of amino acids (Haugen and Pettigrew, 1985) and availability of lysine, as determined by the slope-ratio assay (Batterham et al., 1986). In an evaluation of 23 commercially processed meat and bone meals, Knabe (1989) reported that mean ileal amino acid digestibilities for meals processed by the older, higher-temperature batch and Dupps systems had lower digestibilities than meals processed by the newer, lower-temperature, Atlas, Carver-Greenfield and Stordz-Bards systems. Mean lysine and tryptophan digestibilities for the older and newer systems were 76 ± 5 and 65 ± 6% for lysine, and 63 ± 7 and 52 ± 9 % for tryptophan, respectively.

Correcting the low digestible lysine and tryptophan contents of meat and bone meal by additions of feed-grade amino acids allows increased use of meat and bone meal in diets of growing-finishing hogs. Cromwell et al. (1991) fed meat meal as the only source of supplemental protein in corn-based diets of finishing pigs with either lysine, or lysine plus tryptophan supplementation. Diets contained 10% meat meal. Compared to the control, soybean meal-supplemented treatment, the meat meal diet without tryptophan supplementation reduced daily gains 42%, and worsened feed efficiency 28%; adding .05% L-tryptophan to the meat meal diet resulted in performance similar to that found on the control diet. Knabe (1989) also reported equal performance for growing-finishing pigs fed diets based on soybean meal or containing up to 8% meat and bone meal when digestible lysine and tryptophan were equalized across treatments.

The high mineral content of meat and bone meal was once thought to be a factor responsible for the reduced performance of pigs fed high levels of meat and bone meal (Eastoe and Lacy, 1960). Subsequent reports (Evans and Leibholz, 1979) show this not to be true. The reduced performance with increasing bone content of meat and bone meal likely reflects the reduced quality of the protein due to higher collagen content and possible interactions between high calcium content and other dietary ingredients such as phosphorus and zinc.

Meat and bone meal and meat meal consistently cost more than soybean meal, but are often used in least-cost diet formulations due to their amino acid profile and phosphorus content. Current data indicates that the old recommendations of no more than 3 to 5% meat and bone meal in swine diets are not nutritionally valid, if the formulator has accurate nutrient content for the meals, and formulates to adequate digestible lysine and tryptophan levels. Meat and bone meal and meat meal content will likely never exceed 5 to 7% of the diet, however, because at that level, the need for dietary available phosphorus is usually met and the cost advantage of meat and bone meal diminishes.

The meat and bone and meat meals are usually not included in diets of pigs weighing less than 40 lb. The young-weaned pig requires highly-digestible and palatable ingredients for maximum performance.

Poultry By Product Meal. Based on its nutrient profile and high digestibility, poultry-by product meal should be an excellent protein feedstuff for use in swine diets. Research reports on use of the meal in swine diets could not be found. Scarcity and cost of the meal likely prohibits its routine use in swine diets. Most of the meal is either sold to pet food manufacturers at prices that prohibit its economical use in swine diets, or it is retained by the vertically integrated poultry producers for use in broiler and layer diets.

Hydrolyzed Feather Meal. Low digestible lysine and histidine content limit the use of feather meal in swine diets. A recent report (Chiba et al., 1996) found that up to 9% feather meal could be used in isolysinic corn-soybean meal diets of the finishing pig without adversely affecting carcass merit, but 3% feather meal was the maximum usage rate without reducing performance. Use of feed-grade lysine and 9% feather meal to replace all of the soybean meal resulted in lowered performance compared to the soybean meal control.

A unique use of feather meal is to provide excess protein in diets of growing-finishing swine (Chiba et al., 1995) and broilers (Cabel et al., 1988) to reduce fat deposition. Feeding up to 15% feather meal (24% protein diets) in lysine adequate corn-soybean meal diets of finishing pigs did not reduce performance but reduced backfat depth and increased leanness; however, the response in carcass leanness was marginal and likely would be uneconomical. The potential for use of feather meal in amino acid supplemented diets is shown by the work of Chung and Baker (1994) to determine methionine requirements of the young weaned pig. Pigs fed corn-soybean meal-dried whey diets containing 15.5% feather meal and supplemented with lysine, histidine, and methionine had performance equal to that of pigs fed the control diet without feather meal.

In practice, levels of feather meal in swine diets will be kept low to obtain maximum performance. As with meat and bone meal, feather meal should not be fed to young-weaned pigs.

Menhaden Fishmeal. Menhaden fishmeal is a unique rendered product in that the entire fish is rendered instead of just the inedible portions of an animal, as with meat and bone meal. This results in a meal with excellent protein quality, high energy content, and high calcium and phosphorus contents. Properly processed menhaden fishmeal can be the only source of supplemental protein in swine diets if adequate digestible lysine and tryptophan contents are maintained in the diet. In practice, however, fishmeal is not fed to growing-finishing pigs due to its high cost. Also, including too much fishmeal (in excess of 1% fish oil) in diets of finishing pigs will result in off-flavored pork due to incorporation of fish fatty acids and other lipids directly into the adipose tissue.

Menhaden fishmeal is best suited to the nutrient dense, highly-digestible diets needed by the pig weaned at 21 to 28 days of age. The high cost of menhaden fishmeal can be justified in these diets. Menhaden fishmeal at levels up to 12% of the diets fed during the 8 to 14 or 8 to 21 day periods after weaning (phase II type diets) have been shown to improve pig performance over isolysinic control diets containing soybean meal (Stoner et al., 1990) This response cannot be explained by differences in nutrient content. The lower antigenecity of fishmeal than soybean meal for the weaned pig may be partially responsible for this effect. In practice, 3 to 5% menhaden fishmeal is often included in phase II diets of pigs weaned at 21 days of age due to its ability to stimulate performance.

Quality of menhaden fishmeal is affected by processing conditions, and storage conditions of fish during the time period between being harvested and processed. Rancid fishmeal or fishmeal with excessive oil or salt, content is not uncommon. Processors now market "select" or "premium" fishmeals for use in diets of the young pig to ensure quality. These higher quality meals are more digestible by the young pig. Three "select" fishmeals had ileal lysine digestibilities of 87, 86, and 86 % compared to 65% for a menhaden fishmeal that was noticeably rancid (Knabe, personal communication).

Dried Blood Products. Properly processed blood meals are excellent protein feeds for swine, when used in limited quantities to ensure adequacy of dietary isoleucine. Of all the common protein feeds, blood meal has the highest lysine content expressed as either a percentage of the sample, or as a percentage of protein.

Spray-dried and ring dried whole blood are vastly superior to the older vat-dried blood meals. Vat dried blood meals have very low nutritional value due to heat damage of the protein. In a comparison of two vat-dried blood meals, spray dried blood meal and ring dried blood meal, Knabe (1989) reported ileal lysine digestibilities of 45, 66, 95, and 85%, respectively. Low levels of spray dried bloodmeal are often used in phase II diets of the weaned pig due to the improved performance which justifies its high cost. Depending upon differences in cost, spray dried bloodmeal may replace the fishmeal used in phase II diets. Kats et al. (1994b) concluded that 2% spray dried bloodmeal (either porcine, bovine, or avian blood) was the optimum level for phase II diets to improve performance of pigs weaned at 21 days of age. Performance of pigs fed diets containing 2.5%spray dried bloodmeal was superior to performance of pigs fed diets containing 5% menhaden fishmeal. They also reported no response to bloodmeal in pigs beyond 42 days of age.

In summary,spray dried bloodmeal is an excellent feed for phase II diets of the weaned pig, but its high cost, and lack of improvement in performance of pigs beyond 42 days of age precludes its use in other swine diets.

Spray dried porcine plasma contains non nutritive factors that stimulate feed intake in the 14 to 21 day old weaned pig (Sohn et al. 1991; Ermer et al. 1992; Hansen et al. 1993; Kats et al., 1994a). Use of this product at 5 to 7.5% of the phase I diet has essentially eliminated the post-weaning lag in performance common to weaned pigs. This is a short-term response, in that once pigs are adapted to dry feed intake by 7 days after weaning, the response to spray dried plasma is diminished.

Due to its high cost, spray dried porcine plasma is fed at the lowest levels and for the shortest period possible. Goodband et al. (1994) concluded that phase I diets, fed for the first 7 days after weaning, should contain 7.5% spray dried porcine plasma if pigs are 21 days of age or less at weaning and weigh less than 15 lb. Once pigs achieve 15 lb, they should be fed phase II type diets containg spray dried blood meal, and/or fish meal.

Rendered Fats

Factors Affecting Energy Content.

Fats and oils are the most energy dense feeds that can be fed topigs, containing on average about 2.25 times the energy of an equal weight of carbohydrate or protein. They are also a very diverse commodity varying in fatty acid composition, amount of free fatty acids and unsaponifiable material. Fatty acid composition and level of free fatty acids affects digestibility of the fat; unsaponifiable material and other non-lipid material affect the gross energy of the fat.

To be absorbed from the digestive tract, the fat must form micelles with bile salts in the intestinal lumen. The efficiency with which this is done is affected by length of the fatty acid, and saturation of the fatty acid.

Short and medium chain fatty acids (14 carbons or less) readily form micelles. Apparent digestibility of fat sources high in medium chain fatty acids in pigs is high (80 to 95%) regardless of the level of saturation (Freeman et al. 1968; Frobish et al., 1970; Braude and Newport, 1973).

In pigs, saturated fatty acids alone have a lower micellar formation potential and thus are less efficiently digested than unsaturated fatty acids (Freeman et al., 1968). However, micelle formation and absorption of saturated fatty acids is increased in the presence of unsaturated fatty acids or monoglycerides as reviewed by Freeman (1984). Therefore, the ratio of unsaturated to saturated fatty acids (U/S) is important in evaluating the potential energy content of a fat.

Powles and co-workers (1993, 1994) reported that for both the growing pig (25 kg) and the young weaned pig (35 d of age, 10 kg) apparent fat digestibility increased with increasing U/S ratio. Tallow with a U/S ratio of about 1 was 79.5 and 88.4%

digestible in growing and weaned pigs, respectively, compared to 91.2 and 94.2% for soybean oil that had a U/S ratio of about 5.7. The type of response to increasing U/S ratio differed by age; the response was exponential for growing pigs with a U/S ratio of about 2.0 maximizing digestibility but linear for the young pig with consistent improvements up to 5.7 U/S. In a review of five experiments, Stahly (1984) reported that a U/S ratio of 1.5 to 2.0 was needed for high digestibility of fats in growing-finishing pigs.

Fat blends incorporated into pig diets may contain high levels of free fatty acids. Increasing free fatty acids by use of acid hydrolysates of tallow and soybean oil caused linear reductions in fat digestibility of the weanling and growing pig (Powles et al., 1993, 1994). On average, each increase in free fatty acid content of 10 percentage units reduced digestibility and DE content of the fat by about 1.5 percentage units. The reduced digestibility with increasing free fatty acid content suggests that a certain quantity of monoglycerides must be present for the formation of micelles.

Table 13 shows reported energy content for animal fats. The variation among reports likely reflects differences in methodology and differences in the fats evaluated. As mentioned earlier, fats have a low heat increment so NE is high. In the report by Noblet et al. (1993), for example, animal fat contained 1.84 times the DE of wheat, but 2.4 times the NE of wheat.

Powles et al. (1995) recently reported regression equations to estimate energy content of fats based on U/S ratio and free fatty acid content. The U/S ratio and free fatty contents suggested by NRA (1992) were used to calculate the DE content of feed grade animal fats shown in Table 13.

Use of Fats in Swine Diets

The primary reason for adding fat to swine diets is to increase energy content. Adding fat also reduces dust in swine buildings, which benefits both pigs and humans. Chiba et al. (1985) reported that adding 5% tallow to ground, meal-type diets reduced aerial dust about 50% and tended to lower lung lesion scores in pigs fed fat. Adding fat also lubricates and extends the life of feed mixing equipment.

Growing-finishing pigs. Adding fat to diets of growing-finishing pigs consistently improves feed efficiency and lowers voluntary feed intake. Pettigrew and Moser (1991) summarized 92 experiments evaluating supplemental fat in diets of growing-finishing pigs. On average, pigs fed fat grew .04 kg faster each day (78% of the experiments had a positive response), consumed .10 kg feed less each day (83%

positive responses) and had an improved gain/feed ratio of .04 (95% positive responses). Average backfat also increased .17 cm (67% positive responses). The degree of response in each trait was dependent on the level of fat inclusion. Daily gains improved up to 5% added fat, and thereafter decreased with increasing fat content. Daily feed intake was slightly increased at fat levels of 3% or less, but decreased at higher levels. Gain:feed ratio and backfat increased consistently as the level of added fat increased.

Fat supplementation appears most beneficial when pigs are kept in thermal neutral or hot environments, due to the lower heat increment of fats. Stahly et al. (1981) reported that the addition of 5% tallow to diets of growing-finishing pigs improved daily gains 8% and feed efficiency 12%, compared to 1% and 8% responses, respectively, for pigs fed in the winter. Feeding fat in the summer increased ME intake over control pigs only 3%, but the lower heat increment of fats would have resulted in considerably higher net energy intakes. This increased energy intake is likely responsible for the 3% increase in backfat noted in the report. The effect of enviornmental temperature on utilzation of fats is discussed in detail by Stahly (1984).

To obtain the most benefit from added fat, concentration of other nutrients in the diet should be expressed as a proportion to energy content. Simply adding fat to an existing diet may result in an amino acid or mineral deficiency due to the lower feed intake of pigs fed fat. Inadequate lysine/energy ratios lower performance and carcass leanness (Chiba et al. 1991ab).

The ultimate decision to use fat in swine diets is one of economics, and feasibility of handling and mixing fats in a given mill. Adding fat consistently improves feed efficiency, improves growth under the correct environmental conditions, but also lowers carcass leanness due to increased fat deposition. The recent merit buying systems based on carcass leanness suggests that feed cost/lb of gain will no longer be an adequate method of evaluating the economics of fat additions.

Weaned pigs. Fats are added to diets of weaned pigs primarily to improve performance. Long-term effects on carcass merit are not a concern. In a summary of 92 experiments, Pettigrew and Moser (1991) reported a small .01 kg advantage in daily gains (40% positive responses), a .05 kg reduction in daily feed intake (64% positive responses), and a .04 increase in gain/feed (71% positive responses) from feeding fats. The response to added fat is less consistent for the weaned pig than for the growing-finishing pigs.

The ability of the young weaned pig to digest animal and vegetable fat is age dependent. The pig efficiently digests the fat in sow's milk (Frobish et al., 1967), but when provided the long-chain fatty acids present in animal fats and vegetable oils during the immediate post-weaning period, digestibility drops, then recovers by the end of the first 14 days post-weaning (Cera et al., 1988ab). Benefits in performance from adding fat during the post-weaning period reflect these differences in digestibility. Adding 3 to 6% soybean oil did not improve performance of pigs weaned at 21 days during the first 14 days post-weaning, but improved feed efficiency during the 15 to 35 day post-weaning period Howard et al. (1990).

Although young weaned pigs may not efficiently utilize fats during the immediate post-weaning period, diets of weaned pigs typically contain fats to minimize dust, and to improve pelletting of phase I and II diets containing milk products. Quality of the fat fed to weaned pigs is important. Rancid fats and fats with high free fatty acid content may lower palatability and reduce growth rates.

Lactating sows. Fats are best utilized in the breeding herd by the lactating sows. Increasing energy density by adding fat reduces voluntary daily feed intake, increases ME intake, reduces weight loss in the sow and increases litter weaning weights (Pettigrew and Moser, 1991). As with growing-finishing pigs, the greatest response to added fat will likely occur in the summer when heat stress reduces voluntary intake (Schoenherr et al., 1987). A large cooperative study (Coffey et al., 1994) examined the interaction of energy intake during gestation and energy density in lactation on reproductive performance. Inclusion of 9% fat in the lactation diets improved pig weaning weights 8%.

Feeding high levels of fat to sows just prior to farrowing and during lactation has been shown to increase lipid content of both colostrum and milk about 2 percentage units (Seerly et al., 1978), this increase in fat content is associated with increased survival of piglets under certain conditions, as reviewed by Pettigrew (1981) and Pettigrew and Moser (1991). For a benefit in survival rate, adequate amounts of fat must be fed prior to farrowing and survival rate must be low. Pettigrew (1981) initially reported that feeding at least 1 kg of fat prior to farrowing and a survival rate of 80% or less was required to obtain a response to added fat. In his subsequent review, he revised his estimate of survivability to 70 to 80% to obtain positive response to added fat. Survivabilities that low are uncommon in modern farrowing facilities.

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Table 1. Pattern of Amino Acids in the Ideal Protein, as Proposed by Different Research Groups

Amino acid	ARC[a]	NRC[b]	Wang and Fuller[c]	Chung and Baker[d]	Hahn and Baker[e]
Lysine	100	100	100	100	100
Leucine	100	74	110	100	100
Phe + Tyr	96	81	120	95	95
Valine	70	59	75	68	68
Threonine	60	59	72	65	70
Met + Cys	50	52	63	60	65
Isoleucine	54	56	60	60	60
Arginine	--	42	42	42	42
Histidine	32	26	32	32	32
Tryptophan	14	15	18	18	20

[a]ARC, 1981.
[b]NRC, 1988.
[c]Wang and Fuller, 1989.
[d]Chung and Baker, 1992; profile for 10 kg pig.
[e]Hahn and Baker, 1995; profile for finishing pigs.

Table 2. Mean Protein Fat, Calcium, Phosphorus and Amino Acid Contents of Meat and Bone Meal and Meat Meal[a]

	Meat and bone meal[b]			Meat meal[c]		
Nutrient, %	n	Mean	SD	n	Mean	SD
Crude protein	255	51.4	2.64	171	54.0	2.93
Crude fat	78	10.70	1.61	35	10.72	1.55
Calcium	255	9.99	1.01	171	7.69	1.16
Phosphorus	255	4.98	.38	171	3.88	.41
Arginine	61	3.60	.35	22	3.34	.57
Histidine	62	.92	.19	22	.95	.28
Isoleucine	62	1.40	.25	22	1.58	.21
Leucine	62	3.10	.47	22	3.32	.49
Lysine	64	2.64	.36	22	2.85	.47
Methionine	39	.70	.14	7	.79	.18
Cystine	7	.46	.23	7	.45	.26
Phenylalanine	62	1.67	.22	20	1.98	.58
Threonine	64	1.65	.23	22	1.74	.33
Tryptophan	29	.26	.05	2	.29	.05
Valine	62	2.11	.34	22	2.44	.43

[a]As-fed basis. Data for protein, fat, calcium and phosphorus from commercial sources. All amino acid values are from data reported by universities. References are: meat and bone meal, 2, 3, 4, 5, 7, 49, 55, 60, 66, 76, ; meat meal, 4, 27, 28, 30, 40, 41, 46.

[b]Protein, fat, calcium and phosphorus contents for meals having at least 4.4% phosphorus. The mean protein content of meals analyzed for amino acids was 50.5±4.3.

[c]Protein, fat, calcium and phosphorus contents for meals having less than 4.4% phosphorus. The mean protein content of meals analyzed for amino acids was 54.9±2.1.

Table 3. Regression of Amino Acid Contents and Crude Protein in Meat and Bone Meal and Meat Meal

Amino acid	n	Equation	r
Arginine	70	$y = .8516 + .0546x$	.70
Histidine	70	$y = -.4639 + .0278x$	.57
Isoleucine	70	$y = -.4802 + .0373x$	.67
Leucine	70	$y = -1.1133 + .0841x$	.78
Lysine	70	$y = -.3367 + .0591x$	.69
Methionine	45	$y = -.3125 + .0202x$	.66
Phenylalanine	68	$y = -.2145 + .0377x$	.63
Threonine	70	$y = -.6008 + .0448x$	.78
Tryptophan	27	$y = -.0113 + .0055x$	.57
Valine	70	$y = -.6981 + .0565x$	.64

Table 4. Mean ± Standard Deviation of Crude Protein, Calcium, and Phosphorus Contents for Meat and Bone Meals from Different Renderers[a]

		Crude protein			Calcium			Phosphorus		
Renderer	n	Mean	SD	%<50%	Mean	SD	%<8%	Mean	SD	%<4.4%
1	24	50.6	2.1	38	8.2	1.3	38	4.2	.6	33
2	38	50.0	1.3	47	10.8	.7	0	5.2	.3	0
3	24	54.6	2.8	8	7.5	1.3	63	3.9	.6	50
4	27	56.8	1.2	0	6.3	1.1	93	3.6	.6	93
5	29	51.5	.7	7	8.9	.5	0	4.2	.3	83
6	65	51.4	1.8	22	10.0	1.1	6	5.1	.4	2
7	23	55.8	1.7	0	8.4	1.0	48	4.4	.4	9
8	23	56.4	2.1	0	8.1	1.0	52	4.3	.4	13
9	18	51.3	1.1	11	10.6	.4	0	5.2	.2	0

[a]Data provided by a feed manufacturer for a 6 month period in 1994.

Table 5. Mean Apparent Ileal Digestibility of Protein and Amino Acids in Meat and Bone Meal and Meat Meal[a]

Nutrient, %	Meat and bone meal			Meat meal		
	n	Mean	SD	10	Mean	SD
Crude protein	30	66	5.4	2	78	3.5
Arginine	30	80	3.7	8	73	9.4
Histidine	30	68	7.2	8	79	3.1
Isoleucine	30	68	7.2	8	63	11.0
Leucine	30	74	5.1	8	69	8.3
Lysine	30	71	6.8	8	68	9.0
Methionine	2	84	2.8	2	84	2.8
Cystine	1	63	-	-	-	-
Phenylalanine	30	77	5.2	8	65	11.6
Threonine	30	64	6.2	8	56	14.8
Tryptophan	29	57	9.4	-	-	-
Valine	30	73	5.2	8	66	9.2

[a]Data reported by universities. References are: meat and bone meal, 2, 7, 49, 60, 55; meat meal, 40, 41, 46.

Table 6. Mean Nutrient Content of Apparent Ileal Digestibility for Spray Dried and Ring Dried Blood Meals[a]

	Content[bc]			Digestibility[d]		
Nutrient, %	n	Mean	SD	n	Mean	SD
Crude protein	20	88.0	3.98	10	87	4.1
Arginine	19	3.64	.35	10	90	5.1
Histidine	20	5.39	.52	10	95	2.6
Isoleucine	20	.93	.18	10	67	10.2
Leucine	20	11.16	.67	10	92	2.9
Lysine	20	8.24	.55	10	94	2.1
Methionine	17	1.15	.34	10	84	5.4
Cystine	10	1.12	.11	--	--	---
Phenylalanine	20	6.17	.44	10	92	2.9
Threonine	20	3.93	.50	10	86	3.9
Tryptophan	13	1.12	.30	7	92	5.1
Valine	20	7.76	.64	10	92	2.7

[a]As-fed basis.

[b]References are: 45, 50, 51, 56, 59, and 61 for spray dried blood meal and 4, 60, and 61 for ring dried blood meal.

[c]A feed manufacturer reported a protein mean ± SD of 89.3 ± 2.9% for 97 samples of spray dried blood meal and a dry mattercontent of 89.4 ± 1.7 for 79 samples. An additional feed manufacturer reported a protein content of 89.6 ± 3.2% for 16 samples of ring dried blood meal.

[d]References are 56 and 59 for spray dried blood meal and 60 for ring dried blood meal.

Table 7. Mean Nutrient Content and Apparent Ileal Digestibility of Protein and Amino Acids in Spray Dried Porcine Plasma

	Content[ab]		Digestibility[c]	
	Mean	SD	Mean	SD
Crude protein	70.8	5.4	78	7.1
Arginine	4.25	.35	86	6.3
Histidine	2.33	.52	89	2.8
Isoleucine	2.75	.18	83	3.5
Leucine	7.03	.67	83	1.4
Lysine	6.33	.55	86	2.1
Methionine	.68	.34	63	2.1
Cysine	2.36	.09	--	--
Phenylalanine	4.15	.26	85	5.0
Threonine	4.22	.23	80	3.5
Tryptophan	1.29	.21	92	-
Valine	4.77	.14	84	3.5

[a]As fed basis.

[b]Based on four samples except cystine which is based on two samples. References are 45, 50, 56, and 59.

[c]Based on two samples except tryptophan which is based on one sample. Reference is 59.

Table 8. Mean Nutrient Content and Apparent Ileal Digestibility of Poultry-by-Product Meal[a]

Nutrient, %	Content, %[b]			Digestibility, %[c]		
	n	Mean	SD	n	Mean	SD
Crude protein	59	64.1	2.60	6	76	3.1
Calcium	28	4.46	.50			
Phosphorus	28	2.41	.19			
Ash	31	14.4	1.44			
Dry matter	27	95.1	1.79			
Crude fat	45	12.6	1.47			
Arginine	28	4.47	.52	6	87	2.3
Histidine	27	1.34	.16	6	80	4.4
Isoleucine	28	2.35	.27	6	79	2.0
Leucine	28	4.49	.49	6	81	4.4
Lysine	29	3.73	.57	6	84	4.6
Methionine	21	1.23	.12	-	-	-
Cystine	21	.99	.37	-	-	-
Phenylalanine	28	2.47	.35	6	83	3.5
Threonine	29	2.46	.22	6	74	3.6
Tryptophan	13	.53	.12	6	74	11.5
Valine	28	2.96	.51	6	78	2.6

[a]As-fed basis.

[b]References are: 7, 25, 30, 43, 52, 60, 66, 68, 55.

[c]References are: 7, 60, 55.

Table 9. Mean Nutrient Content and Apparent Ileal Digestibility of Protein and Amino Acids in Feather Meal

Nutrient, %	Content, %[a]			Digestibility, %[b]
	n	Mean	SD	
Crude protein	23	82.9	5.0	63
Ash	13	2.7	1.3	-
Dry matter	20	93.3	2.9	-
Crude fat	13	5.2	1.7	-
Arginine	23	5.99	.80	79
Histidine	21	.81	.32	35
Isoleucine	22	3.99	.46	75
Leucine	22	6.90	.58	75
Lysine	23	1.80	.30	40
Methionine	20	.61	.12	-
Cystine	20	4.61	.51	-
Phenylalanine	20	4.07	.30	80
Threonine	22	3.79	.43	66
Tryptophan	3	.59	.19	60
Valine	22	6.37	.68	77

[a]As-fed basis. References are: 16, 17, 30, 43, 44, 60, 61, 66, 69. A feed manufacturer submitted data on 31 samples; mean±SD for crude protein and crude fat were, respectively: 85.7 ±1.6%, 6.0 ±1.5%.

[b]Reference 60. Only one sample evaluated.

Table 10. Mean Nutrient Content of Menhaden Fish Meals[a]

	Normal[b]			Normal[c]		Select[d]	
Nutrient, %	Mean	SD	n	Mean	SD	Mean	SD
Crude protein[e]	62.8	1.05	8	60.8	1.18	62.2	1.53
Calcium	5.16	.24	4	5.10	.57	5.28	.28
Phosphorus	3.24	.15	4	3.28	.46	2.81	.14
Ash	17.2	.88	7	18.6	.73	-	-
Crude fat	9.9	.70	3	7.9	.74	9.5	.20
Arginine	3.68	.13	7	3.64	.20	3.61	.21
Histidine	1.52	.15	7	1.21	.21	1.56	.10
Isoleucine	2.35	.11	7	2.59	.05	2.26	.08
Leucine	4.33	.11	7	4.45	.09	4.12	.15
Lysine	5.00	.15	8	4.78	.45	4.49	.21
Methionine	1.98	.12	5	1.83	.11	1.72	.14
Cystine	.62	.07	1	.60	-	.45	.04
Phenylalanine	2.38	.12	7	2.45	.18	2.25	.11
Threonine	2.64	.09	7	2.53	.11	2.66	.10
Tryptophan	.54	.05	5	.49	.03	.53	.07
Valine	3.00	.13	7	3.01	.10	2.66	.14

[a]As-fed basis.

[b]Data for 24 samples provided by one fish meal manufacturer.

[c]References are: 56, 57, 60, 83.

[d]Data for 24 samples provided by one feed manufacturer. The meals were used in pig starter diets.

[e]An additional feed manufacturer reported 62.6 ±.9% as the crude protein content of 20 samples of normal Menhaden fish meal. An additional feed manufacturer reported 63.0 ±1.3% as the protein content of 39 samples of select Menhaden fish meal.

Table 11. Apparent Ileal Digestibility of Menhaden Fish Meals

	Digestibility, %		
	n	Mean	SD
Crude protein	7	70	6.9
Arginine	7	85	5.6
Histidine	7	75	8.6
Isoleucine	7	80	6.6
Leucine	7	81	6.2
Lysine	7	81	8.0
Methionine	4	81	7.7
Cystine	-	-	-
Phenylalanine	7	79	6.5
Threonine	7	74	7.5
Tryptophan	5	77	4.3
Valine	7	78	6.8

References are: 56, 57, 60.

Table 12. Estimates of Energy Content of the High-Protein Rendered Feeds[a]

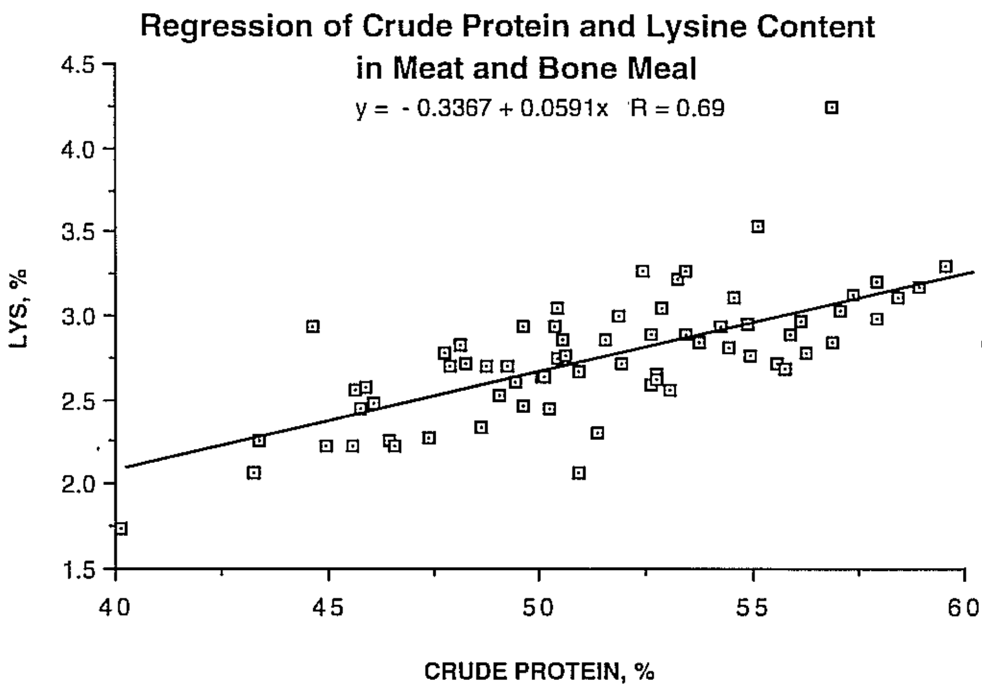
Feedstuff	Mcal/kg	
	DE	ME
Blood meal, spray dried	2.98	2.33
Feather meal	2.73	2.21
Fish meal, menhaden	3.80	3.30
Meat and bone meal	2.54	2.28
Meat meal	2.81	2.42
Soybean meal, 44%	3.49	3.22
Corn	3.53	3.42

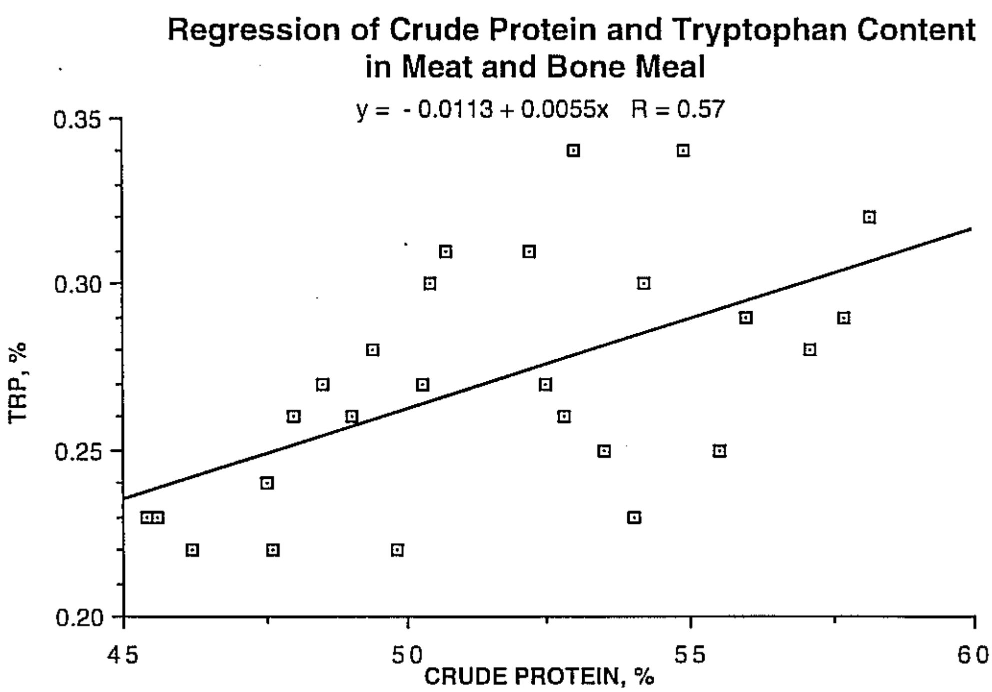
[a] Values from NRC (1988).

Table 13. Reported Energy Contents for Animal Fat

Reference	Description	Mcal/kg DE	Mcal/kg ME	Mcal/kg NE
NRC (1988)	Tallow	8.20	7.90	
	Lard	7.86	7.75	
	Poultry, fat	8.64	7.98	
Stahly (1984)	Tallow		7.89	
	Tallow		7.88	
	Lard		7.99	
	Lard		7.70	
Morgan et al., 1984	Tallow		9.27	
Wiseman et al., 1990	Tallow	8.16	7.77	
Powles et al., 1993	Tallow	7.46		
	Tallow	8.08		
Powles et al., 1994	Tallow	8.20		
Noblet et al., 1993	Animal fat	7.12	7.06	7.00
Powles et al., 1995[a]	Tallow	8.05		
	Choice white grease	8.38		
	Yellow grease	8.45		
	Poultry fat	8.56		

[a]Based on equations given by Powles et al. (1995) for growing pigs and U/S ratios and free fatty acid content reported by NRA (1990).


Regression of Crude Protein and Lysine Content
in Meat and Bone Meal
y = - 0.3367 + 0.0591x R = 0.69
LYS, %
4.5
4.0
3.5
3.0
2.5
2.0
1.5
40
45
50
55
60
CRUDE PROTEIN, %


Regression of Crude Protein and Tryptophan Content
in Meat and Bone Meal
y = - 0.0113 + 0.0055x R = 0.57
TRP, %
0.35
0.30
0.25
0.20
45
50
55
60
CRUDE PROTEIN, %