ENERGY AND PROTEIN INTERACTION OF THE LACTATING SOW

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Introduction

Improved genetics, nutrition, housing and management systems have permitted significant increases in milk production of lactating sows. In 1972, Boomgaardt et al. (1972) studied sows that produced about 8.5 pounds of milk daily. In contrast, Johnston et al. (1993) reported daily litter growth rates of 4.86 pounds which equates to an estimated milk production of 19.5 pounds per day. In spite of these large improvements, the genetic potential for growth of nursing piglets is still not realized (Boyd et al., 1995) suggesting that improved nutritional programs that result in increased milk production will increase growth rate of nursing pigs. Heavier pigs at weaning may be of particular importance in modern production systems that implement relatively short lactations (14-18 days).

Lower than desired voluntary feed intake of lactating sows is a constant problem nagging the commercial swine industry. Many factors such as genetics, diet quality, diet composition, and environment influence voluntary feed intake of lactating sows. Time and space do not allow a complete discussion of these and their impact on the nutritional needs of the lactating sow. Our goal is to maximize feed intake of sows during lactation so that the largest possible quantity of feed is available to package the nutrients necessary for lactation.

Energy and protein, or more correctly amino acids, are the two dietary essentials needed in the greatest quantity with the exception of water. Consequently, these two classes of dietary essentials have been the focus of much research in nutrition of the lactating sow. This paper will focus on the lactation period but proper nutrition of the lactating sow begins before farrowing so that the proper stage is set for a successful lactation.

Inter-relation of Reproductive Phases

Phases of the sow’s reproductive cycle are interrelated. Nutrition during one phase of the reproductive cycle influences sow performance in the subsequent phase and beyond. Therefore, a sound feeding program does not focus on nutrition during any one isolated phase of the reproductive cycle but considers the total life cycle of the sow.
Gestation feeding programs are designed to provide sufficient nutrients for development of the fetuses and associated uterine tissues, development of the mammary gland, and modest increases in maternal body weight. If given the opportunity, sows will consume feed far in excess of these needs leading to overly fat sows at farrowing. Several studies worldwide have demonstrated that increasing feed intake during gestation and the associated large increases in sow body weight depress feed intake of lactating sows (Dourmad, 1991; Revell et al., 1994; Weldon et al., 1994) (Figure 1). Low lactation feed intake can depress sow performance and shorten the sow’s reproductive life.

Figure 1. Effect of gestation feed intake on lactational feed intake in gilts (Dourmad, 1991)

Excessive energy intake in late gestation (after day 75) may be detrimental to subsequent milk production. Research conducted at Michigan State University suggests that energy intakes of 10.5 megacalories of metabolizable energy (ME; 7.25 pounds corn-SBM diet) per day during late gestation reduces the amount of milk secreting tissue in the mammary gland compared with gilts fed 5.75 megacalories of ME (4 pounds corn-SBM diet) daily (Weldon et al., 1991). Australian researchers observed that fat gilts had fewer milk secreting cells in their mammary glands than did lean gilts (Head et al., 1991; Head and Williams, 1991). It is not clear if these differences in cell numbers will translate into differences in milk production after farrowing. In contrast to effects of elevated energy intake, increasing lysine intake from 4 to 16 grams per day (NRC recommends 8.2 grams/day) had no effect on number of milk secreting cells in the mammary gland (Kusina et al., 1995b) but did increase milk production (Kusina et al., 1995a).

Nutrient intake during lactation has profound effects on postweaning reproductive performance. Low energy (Reese et al., 1982; Johnston et al., 1989) or protein (O’Grady
and Hanrahan, 1975; King and Dunkin, 1986) intake during lactation is associated with increased loss of body tissue and delayed return to postweaning estrus.

These three examples demonstrate the importance of developing a feeding program for the sow’s entire reproductive cycle rather than focusing on one particular phase at the exclusion of others. Lactation is the most challenging phase of the reproductive cycle from a nutritional viewpoint. Consequently, this phase has been the subject of many experiments and will be the focus for the remainder of this paper.

### Energy and Protein Needs in Lactation

Interactive effects of energy and protein. MacLean (1968) observed that sows weaned in thin body condition experienced a delayed return to postweaning estrus. This increased incidence of suboptimal reproductive performance in thin sows was referred to as the “Thin Sow Syndrome”. Producers and researchers mistakenly believed that the thin condition at weaning was due to excessive mobilization of body fat throughout lactation and that increasing energy intake would correct the problem. However, Brendemuhl et al. (1987) reported that sows fed high energy, low protein diets during lactation lost similar total body weight but less backfat than sows fed low energy, high protein diets. Thus, composition of weight loss may vary depending on which dietary essential, energy or protein, is deficient and which tissue, fat or muscle, is mobilized. Furthermore, about 79% of the lysine that is present in milk proteins is derived from the diet in multiparous sows (Koehler et al., 1996). Consequently, the remaining 20% of lysine present in milk proteins must be derived from endogenous sources. These studies demonstrate that body proteins in muscle and other tissues are an important source of amino acids and energy for the lactating sow.

The sow’s ability to mobilize fat or muscle tissue suggests that one cannot consider the energy and amino acid content of diets separately. Work conducted at the University of Minnesota (Tokach et al., 1992) with primiparous sows demonstrated that under relatively high energy intake the lysine requirement for maximal milk production was 45 grams per day or higher while under low energy intake the lysine requirement was only about 27 grams per day (Figure 2). In the low energy intake scenario, lysine intake above 27 grams per day did not elicit increased milk production presumably because available energy was limiting. So, the “correct” answer for the lysine requirement of the sows in this study would be 27 or 45+ grams per day depending on the sow’s voluntary energy intake.
Energy. Energy is the most difficult dietary essential to supply in the diet of lactating sows in adequate amounts. In most cases, lactating sows do not consume enough feed to supply their daily energy needs. Lactating sows possess a tremendous drive to produce milk and will cannibalize maternal body tissues to satisfy the energy demands of lactation. As daily energy intake increases, loss of body weight declines during lactation and this shortens the interval to first postweaning estrus (Nelssen et al., 1985; Johnston et al., 1989). The challenge for swine producers is to maximize energy intake during lactation. Maximization of energy intake can be achieved by increasing the energy density of the diet and(or) increasing the total quantity of feed consumed.

The most common method of increasing the energy density of the diet is to add fat. Pettigrew and Moser (1991) summarized over 20 experiments reported in the scientific literature in which fat was supplemented to sow diets (Table 1). They found that fat supplementation of sow diets consistently decreased voluntary feed intake but increased daily energy intake. This increased energy intake reduced loss of body weight and supported heavier litter weaning weights. Fat supplementation of sow diets increases fat content of milk resulting in elevated energy density of milk. This elevation in energy density of milk may be responsible for the heavier litter weights observed with fat supplemented sow diets.
Table 1. Summary of responses to supplemental fat in sow diets

<table>
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<tr>
<th>Trait</th>
<th>Number of Responses</th>
<th>Avg. Response</th>
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</thead>
<tbody>
<tr>
<td>Lactation feed intake, kg/d</td>
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<td>-.189&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>ME intake, Mcal/d</td>
<td>19 0</td>
<td>1.24&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Lactation weight change, kg</td>
<td>11 4</td>
<td>1.5&lt;sup&gt;c&lt;/sup&gt;</td>
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<tr>
<td>Weaning to estrus interval, d</td>
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<td>-.56</td>
</tr>
<tr>
<td>Litter weaning weight, kg</td>
<td>18 6</td>
<td>1.65&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup>Pettigrew and Moser, 1991  
<sup>b</sup>P < .001  
<sup>c</sup>P < .05  
<sup>d</sup>P < .01

Another method of increasing energy intake is to increase feed intake. Researchers have wondered how the sow would respond if feed intake and thus energy intake could be increased above the amount she would consume on a voluntary basis. Matzat et al. (1990) fed multiparous sows at 120% of ad libitum feed intake through a cannula placed in the sow’s stomach during lactation (superalimentation). They reported that superalimented sows gained body weight and backfat depth and increased milk yield from 7.8 to 8.6 kilograms per day. These increases in milk yield supported increased litter weight gains from 1,590 grams per day for control litters to 2,078 grams per day for litters nursing superalimented sows. These data suggest that the “extra” energy consumed as a result of increased energy intake will not be funneled entirely into milk production. Some of the energy consumed goes to body stores which may improve rebreeding performance. Rebreeding performance and milk production probably have different economic values. At some point, our sow nutrition schemes will become refined enough to determine the marginal economic value of each additional unit of energy intake.

Historically, nutritionists have discussed energy nutrition in terms of the total calories of energy required for a given biological function with little regard for the source of those calories. Researchers in Mexico demonstrated that a diet containing 50% cane molasses, a readily available source of carbohydrates, fed during the postweaning period increased circulating insulin levels in sows and resulted in a larger litter size at the next farrowing compared with sows fed an isocaloric diet containing added fat (Rodriquez-Marquez and Cuaron, 1990). Other basic research suggests that a diet high in starch elicits higher insulin levels in blood and greater activity of luteinizing hormone in sows compared with a diet of similar energy density but supplemented with fat (Kemp et al., 1995). Luteinizing hormone plays a key role in initiating occurrence of postweaning estrus. While these basic research studies suggest that composition of the diet can have a direct influence on metabolism of the sow, recent experiments at our research farms have not been able to demonstrate similar responses when including cane molasses in the diet (Johnston et al., 1994) or when substituting starch for fat in isocaloric diets (Lorschay et al., 1996). Our initial attempts were unsuccessful; however, further studies will likely increase our knowledge of the link between diet, metabolism, and reproductive functions.
so that nutritionists can include certain ingredients in the lactating sow’s diet for their
direct effects on body metabolism as well as for their nutrient contribution to the diet.

Until nutritionists and swine producers have a more thorough understanding of any
specific metabolic effects of particular ingredients, feedstuffs will be included in lactating
sow diets based primarily on their nutrient content. Energy content of a feedstuff is an
important consideration. Energy dense feedstuffs are favored over lower energy
feedstuffs because of the importance of maximizing energy intake. The energy
evaluation system used can influence the energy value that is assigned to a particular
feedstuff and hence its suitability for use in lactating sow diets. For example, wheat
midds contains 3,000 kilocalories of ME per kilogram which is about 39% of the ME
present in lard. Under a net energy evaluation system, wheat midds contains 1390
kilocalories of NE which is about 27% of the NE in lard (Ewan, 1991). One may place a
higher nutritional value on wheat midds under a metabolizable energy evaluation system
compared with a net energy evaluation system.

Protein. Dietary amino acids supplied in the form of natural proteins are necessary to
maintain the sow’s body, produce milk, and support growth of maternal body tissues.
The first two needs are essential in the lactating sow. Fulfillment of the third need
usually is deferred until gestation when the nutritional needs are not so demanding. Milk
production consumes the lion’s share of the total amino acids needed by the lactating
sow. The amino acid needs are proportional to the level of milk production. While the
sow requires 10 essential amino acids in the diet, lysine is most often first limiting in
corn-soybean meal based diets. Consequently, much attention is paid to the lysine
requirements of the lactating sow. Estimates of the lysine requirements of lactating sows
fill the scientific literature and range from 19 to 54 grams per day (Pettigrew, 1993).
This wide range of estimated lysine requirements can be explained by differences in milk
production (Figure 3).

Lysine intake during lactation may also influence subsequent reproductive performance.
Increasing lysine concentration of the lactation diet from .62 to 1.51% for primiparous
sows had positive effects on litter growth rate (Table 3). More importantly from an
economic perspective, increasing lysine concentration of the lactation diet increased size
of the subsequent litter (Campbell, 1995). These data suggest that feeding during
lactation sets the stage for sow performance almost four months into the future. Future
research will determine if this response is repeatable in primiparous sows and occurs in
older sows.
Figure 3. Estimation of total lysine requirement of lactating sows in relation to litter growth rate (Pettigrew, 1993).

Table 2. Effects of dietary lysine on performance of lactating gilts

<table>
<thead>
<tr>
<th>Trait</th>
<th>Dietary lysine (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>.62</td>
</tr>
<tr>
<td>Feed intake, kg/d</td>
<td>4.53</td>
</tr>
<tr>
<td>Lysine intake, g/d</td>
<td>28</td>
</tr>
<tr>
<td>Weight loss, kg</td>
<td>26.6</td>
</tr>
<tr>
<td>Backfat loss, mm</td>
<td>2.5</td>
</tr>
<tr>
<td>Pigs weaned/litter</td>
<td>9.0</td>
</tr>
<tr>
<td>Piglet growth rate, g/d</td>
<td>185&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Pigs born next litter</td>
<td>10.3</td>
</tr>
</tbody>
</table>

<sup>a</sup>Campbell, 1995
<sup>bcd</sup>Denotes significant differences among treatment means.

Simply stated, proteins are long chains of amino acids. The amino acids are joined in a very specific order that creates a set ratio of amino acids and this ratio is determined by the animal’s genetic code. An ideal protein is one that supplies all the essential amino acids to the sow with no deficiencies or excesses. Determination of the ideal protein for sows is very difficult because she has amino acid needs for maintenance of body tissue (muscle, bone, skin, mammary gland, etc.), body growth, and milk production. Milk protein represents a large portion of the protein manufactured by a lactating sow so the amino acid pattern of sow’s milk has been used by researchers to approximate the ideal amino acid pattern required by lactating sows. This approach is imperfect but still represents an advance in our understanding of amino acid nutrition of sows.

Amino acid balance becomes an especially important issue when diets for lactating sows contain crystalline amino acids. Amino acid specifications of diets can be satisfied with protein from natural sources or a combination of natural proteins and crystalline amino
acids. Increasing the lysine concentration of a diet with natural proteins will also increase dietary concentrations of other essential amino acids. Generally, the desirable amino acid pattern is maintained. However, use of crystalline lysine will achieve the same objective of increasing final diet lysine concentration but concentration of other essential amino acids is not increased. This alters the amino acid balance of the diet which may or may not have negative effects on sow performance.

Recent research has suggested that high lysine diets for lactating sows that contain crystalline lysine may be deficit in valine, an essential amino acid (Tokach et al., 1993). Corn-soybean meal diets containing .9% lysine and either .75% valine (83% of lysine) or .9% valine (100% of lysine) were fed to lactating sows. Litter size at weaning was not influenced by diet but a 3.2 kilograms advantage in litter weight at weaning was observed for sows that consumed the diet containing .9% valine. The advantage in litter weight was greater in litters that contained greater than 10 pigs. These data suggest that dietary valine should be set at 100% of the lysine concentration. A subsequent study (Richert et al., 1996) conducted at the University of Minnesota in cooperation with researchers at Kansas State University revealed a significant linear increase in litter weight gain as dietary valine concentration increased from .75 to 1.15% in diets that contained .9% lysine. Results of this study suggest that dietary valine should be 117% of lysine to maximize lactation performance of sows.

Presently, the mechanism and repeatability of this valine response is unclear. If the sow truly does require valine at greater than 100% of dietary lysine, it is unclear for what functions the added valine is needed. Measurements of blood flow into and out of the mammary gland of lactating sows suggest that valine uptake represents 88% of the lysine uptake (Trottier and Easter, 1995). Valine concentration in sow’s milk is about 73% of the lysine concentration (Pettigrew, 1993).

The discussion above focuses on the biological implications of dietary valine concentration on sow performance. However, one must consider the economic implications of these data. If future studies substantiate the observation that diets for high producing, lactating sows should contain valine at greater than 100% of the lysine concentration, then one must weigh the value of an additional kilogram of litter weight against the cost of supplying high valine levels in the diet. Synthetic lysine is often used to economically achieve high lysine concentrations in diets for highly productive sows. Dietary valine may be limiting in these diets. This potential valine limitation can be corrected by: 1. removing synthetic lysine and using more soybean meal; 2. supplementing the diet with crystalline valine which presently is not commercially available at a reasonable cost; or 3. including a “valine-rich” protein source in the diet. The added diet costs for each of these solutions must be less than the value of the additional litter weight gain before the swine industry will implement this concept. Future experiments will address the biological issues and determine the proper level of dietary valine for high producing lactating sows. With more complete knowledge of the sow’s valine needs, the swine industry will determine the most profitable way to apply that knowledge.
Young sows (first and second parity) seem particularly sensitive to inadequate amino acid nutrition during lactation. Presumably, this is due to the fact that these females are relatively immature with limited body tissue reserves and have a biological drive to continue growing toward their mature body weight. King (1987) argued that protein intake during lactation seemed to have a greater effect on the postweaning interval to estrus than did energy intake. In a more recent study, increasing lysine intake during lactation from 50 to 66 grams per day had little influence on litter performance but significantly reduced the weaning to estrus interval (Wilson et al., 1996). These observations suggest that young sows may deserve special attention in the form of a specially formulated diet or a topdress for the existing diet to ensure prompt return to postweaning estrus which will help keep that young sow in the herd.

New Issues to Consider with Modern Production Systems

Health status of sows. People who care for animals have known for a long time that sick animals exhibit depressed feed intake and poor performance. These same observations are true for lactating sows. Matzat (1989) observed that sows with rectal temperatures greater than 104°F on day 1 of lactation displayed depressed voluntary feed consumption compared to sows with lower rectal temperatures. More importantly, feed intake of these sows did not return to normal levels until day 7 of lactation. These findings indicate that infections and sickness around the time of farrowing can have significant negative impacts on nutrient intake of lactating sows. This may be of particular importance in production systems that employ very short lactation lengths.

It is no surprise that clinically sick sows would not perform to expected levels. However, the effects of subclinical disease may be more obscure. Researchers at Iowa State University studied the effects of chronic stimulation of the immune system on performance of lactating sows (Sauber and Stahly, 1995). Genetically similar gilts were raised, mated, gestated and farrowed in a high health system for this study. After farrowing, half of the sows were injected with a non-pathogenic stimulator of the immune system to simulate the effects of subclinical disease. Loss of body weight and backfat during lactation, and litter size at weaning were not different between sows that did or did not receive immune system stimulation. However, voluntary feed intake, litter weight gain, and estimated yield of milk energy was depressed as a result of immune system stimulation (Table 3). From this study, one may speculate that even low level disease loads will negatively impact sow performance. This observation supports the notion that high health production systems allow pigs to express a greater proportion of their genetic potential compared with conventional production systems with a lower health status.

| Table 3. Effect of immune system stimulation on performance of lactating sows* |
|-------------------------------|-----------|-----------|-----------------|
| Trait                        | Immune system stimulation |                   |                 |
|                               | No        | Yes       | Sign. level     |
| Sow feed intake, kg/d         | 5.36      | 4.82      | .17             |
Leaner genetics. The continued drive to raise pigs with high lean growth potential and to produce a leaner market hog has predictably generated relatively lean sows at the time of farrowing compared with 10 years ago. On a metabolic body weight basis, the lactational capacity of lean sows is similar to that of fatter sows (Sauber et al., 1994). However, these leaner sows have less energy reserves in fat tissue that can be mobilized in support of lactation which elevates the importance of diet as a source of energy. As the industry continues to employ leaner genetics, it will become increasingly important to focus on factors that can maximize the voluntary feed intake of lactating sows.

Short lactations in Segregated Early Weaning systems. Modern, high health production systems often employ a segregated early weaning (SEW) approach to pig production. Inherent in this system is the use of short (14 to 18 day) lactation periods. Feed intake and the resulting nutrient balance of the sow is just as important in SEW systems as it is in more conventional weaning systems that use longer lactation periods. It appears that nutrient balance in the first 14 days of lactation plays an important role in determining how rapidly a sow will return to estrus after weaning. Research conducted at the University of Minnesota indicates that restriction of dietary energy during any week of a 3-week lactation prolongs the weaning to estrus interval (Koketsu et al., 1996). The goal for short lactations should be the same as for longer lactations, maximize voluntary feed intake.

Methods to Determine Dietary Nutrient Density

The appropriate nutrient density of diets is not the same for all sows during lactation. Consequently, one cannot make blanket recommendations for the energy and protein density of lactation diets and expect those recommendations to satisfy the sow’s nutrient needs. Formulation of diets is farm-specific and depends quite heavily on the genetic potential of the sow and her voluntary feed intake. The first step in determining the appropriate nutrient density is to determine the current level of feed intake during gestation and lactation. This process will reveal if feed intake is inadequate, provide a baseline of intake against which future intakes can be evaluated, and provide nutritionists with information necessary to accurately formulate sow diets for a specific herd.

The second step is to establish nutrient intake goals based on current level of milk production. The most practical method of assessing sow milk production is to measure average daily weight gain of the litter. Using average daily litter weight gain and sow body weight, compare nutrient intake levels for sows with target nutrient intakes given in Table 4. For example, a 180-kilogram sow with a litter gaining 1.8 kilograms per day has a target daily intake of 19.36 megacalories of ME and 46 grams of lysine. The nutrient

<table>
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<th>Sow wt. loss, kg</th>
<th>Sow backfat loss, mm</th>
<th>Litter size weaned</th>
<th>Litter wt. gain, kg</th>
<th>Est. milk energy, Mcal/d</th>
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<tr>
<td></td>
<td>11.8</td>
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<td>36.5</td>
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*Sauber and Stahly, 1995*
intakes listed in Table 4 crudely attempt to account for lysine and protein derived from breakdown of body tissue. We assumed that sows mobilize 4 grams of lysine and 61 grams of protein daily from body tissue during lactation. The energy liberated from mobilization of body tissue is not considered. Consequently, the estimates of daily energy needs assume zero weight loss and may seem higher than is required for commercial production. The values listed in Table 4 should be viewed as intake goals rather than strict requirements.

The third step is to make appropriate management adjustments to maximize nutrient intake during lactation. The fourth step is to determine dietary nutrient concentrations so that daily nutrient intake targets can be achieved with the observed level of feed intakes. Actual nutrient intakes should match target intakes fairly closely if steps one through four were completed successfully. Improper nutrition that does not support optimal milk production during step two when litter gain is being assessed will cause an error in selecting the appropriate level of sow performance on which diet formulations are based. To be sure sows are expressing their full genetic potential for milk production and reproductive performance, producers should challenge their sows with higher daily nutrient intake to determine if sows respond with higher levels of milk production. In addition, other economically important reproductive traits such as re-breeding interval, subsequent litter size, and culling rates must be considered when determining the optimal nutrient density of diets for lactating sows.

Summary

Feeding highly productive sows is a challenging endeavor. Producers and nutritionists should consider the interrelationship among phases of the reproductive cycle when designing a sow feeding program. A better understanding of the interaction among diet, metabolism of nutrients, and reproductive functions will allow us to design more effective feeding programs that improve sow performance. The stepwise procedure presented above will allow sow feeding programs to be tailored to the conditions encountered on individual farms.
Table 4. Recommended energy, protein, total lysine, and digestible lysine intake for lactating sows by level of production$^a$

<table>
<thead>
<tr>
<th>Litter gain (kg/d)</th>
<th>Sow Body Weight, kg</th>
<th>Energy (Mcal ME/d)</th>
<th>Protein (g/d)</th>
<th>Lysine (g/d)</th>
<th>Dig. lysine$^b$ (g/d)</th>
<th>Energy (Mcal ME/d)</th>
<th>Protein (g/d)</th>
<th>Lysine (g/d)</th>
<th>Dig. lysine$^b$ (g/d)</th>
<th>Energy (Mcal ME/d)</th>
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<tr>
<td>1.40</td>
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<td>1183</td>
<td>70</td>
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</table>

$^a$ Adapted from Pettigrew, 1993

$^b$ Assumes 82% apparent ileal digestibility of total lysine
References


