Lohmann Information

NEW DEVELOPMENTS IN SOW NUTRTION IN THE USA

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In this paper, the nutrition of the lactating and gestating sow is briefly reviewed. Recommendations are given for determining the amino acid requirements during lactation and the energy and amino acid requirements during gestation. An ideal feeding pattern during gestation also is proposed.

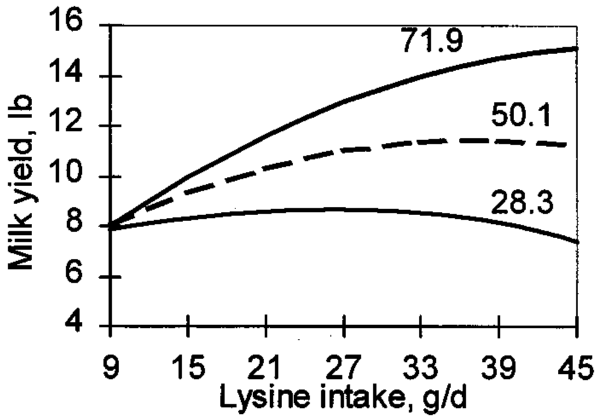
Lactation

Our understanding of the amino acid requirements of lactating sows has improved greatly in recent years. We know that the lysine requirement during lactation is influenced by energy intake. The lysine requirement to minimize muscle loss and improve subsequent reproductive performance is higher than the requirement for milk production. Amino acids other than lysine also are much more important for maximal milk production than previously thought. Each of these areas is addressed in the following sections.

Energy x Protein Interaction

Both amino acid and energy intake are important in influencing lactation and reproductive performance of the lactating sow. The interrelationship between energy and lysine intake is depicted in Figure 1. At low energy intake (28.3 MJ/d), increasing lysine intake from 9 to 45 g/d had little effect on milk yield (Tokach et al., 1992b). However, as energy intake increased to 71.9 MJ/d, the response to greater lysine intake increased markedly. These results reveal that milk yield is dependent on both lysine and energy intake, because the response to one is contingent on the intake of the other. Thus, energy intake must be considered when making lysine recommendations for lactating sows.

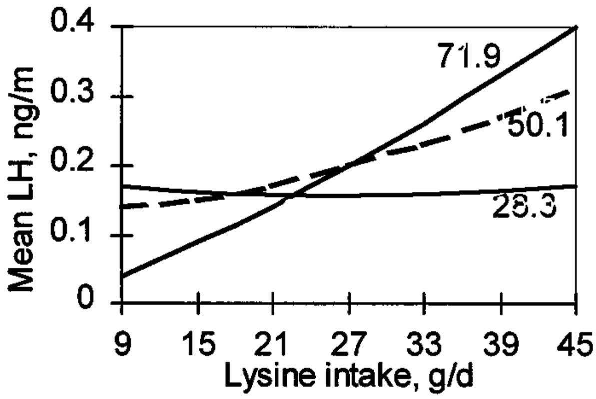
Figure 1:



Influence of lysine and DE (MJ) intakes on sow milk yield.

Energy and lysine intake also influence secretion of reproductive hormones and subsequent reproductive performance in an interactive manner (Figure 2; Tokach et al., 1992c). At low energy intake (28.3 MJ ME/d), increasing lysine intake had little influence on mean LH secretion. The influence of lysine intake on LH secretion increased as energy intake increased. These results reveal that LH secretion, similar to milk production is reduced by restrictions of either lysine or energy intake.

Figure 2:



Influence of lysine and energy intake on LH secretion.

The most practical method of increasing energy intake is to increase total food consumption. The field application of these results is that all steps should be taken to increase total feed consumption during lactation before attempting to customize dietary lysine levels to a particular swine farm. Trials from the University of Minnesota indicate the impact of lactation feed intake on subsequent reproduction increases as weaning age is reduced (Koketsu et al., 1996). Use of high dietary fat levels during lactation will improve litter weaning weights, but may actually impair subsequent reproductive performance by reducing the number of LH peaks in early lactation (Kemp et al., 1995). Limiting intake during lactation should NOT be practiced.

Feed intake during lactation has been a problem on many farms in the U.S. Weaning age has settled between 16 and 21 days of age for most farms. Feed intake in early lactation is critical with these weaning ages to increase weaning weight to make pigs more manageable in the nursery. Lactation feed intake is also critical with older weaning ages. The issue of lightweight pigs entering the nursery is still an issue, although a smaller issue, but the importance of high energy and amino acid intake for subsequent reproduction is still paramount.

Influence of Lysine Intake on Milk Production

Over the years, lysine is the amino acid that has been most intensely investigated. Research by Schoenherr et al. (1988), Stahly et al. (1990), Johnston et al. (1991) and Tokach et al. (1992b) suggested that the lysine requirement was greater for high producing sows than previously suggested. In all of these trials, total protein level of the diet was increased with lysine considered to be the first limiting amino acid. However, every experiment conducted has suggested different requirements for the lactating sow.

The different recommendations from the various experiments are due largely to differences in sow productivity and feed intake. An excellent summary and explanation of the different recommendations for dietary lysine during lactation was presented by Pettigrew (1993). He indicated the driving factor for the different lysine recommendations is the production level of the sows. Pettigrew (1993) performed regression analysis on litter growth rate and lysine intake from several trials and determined that 26 g of lysine is required for every kilogram of daily litter weight gain. A daily maintenance requirement (22 mg/lb.75 BW) or approximately 2 g/d of lysine for a 150 kg (330 lb) sow should be added to this requirement, while the lysine contributed from tissue breakdown (approximately 0.1 g lysine/kg (0.2 g lysine/lb) BW loss) should be subtracted to provide an estimate of the sow's requirement. Based on expected feed intake, the grams/day requirement can be converted into a dietary percentage. For example, if a 150 kg sow weans a litter weighing 61 kg at 21 days, the litter birth weight was 16 kg, and the sow lost 4.5 kg during lactation, the sow would require 56 g lysine/d (45 kg litter gain/21 d = 2.14 kg/d; 2.14 kg/d x 26 g lysine/kg = 56 g lysine for litter gain; 56 g lysine for litter gain + 2 g lysine for maintenance - 2 g lysine from tissue breakdown = daily lysine need of 56 g).

Several factorial methods also have been used to determine the lysine need of the lactating sow. We used a combination of several methods to assemble Table 1. We use this simple chart to determine initial dietary lysine level for a producer, based upon lactation feed intake and litter weaning weight. Lactation feed intake can be determined from feed intake cards or past usage of the lactation diet from records. If the previous lactation diet is higher in lysine than the recommended level from the table, it may be possible to reduce the dietary lysine level without sacrificing performance. If the previous lysine level is lower or the same as the recommendation, the producer may want to increase the lysine (protein) level and reexamine performance records to determine whether litter weaning weight increases. This is a relatively simple approach that has worked well for us to customize sow lactation diets.

Table 1:

Dietary Lysine Level Based Upon Litter Weaning Weight and Sow Feed Intake

litter weight, kg		Lactation feed intake, kg/day								Lysine, g/day
21 d	28 d	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	
45	55	1.05	.90	.80	.70					36
50	61	1.20	1.05	.95	.85	.75				42
55	68		1.20	1.05	.95	.85	.80			48
60	75			1.20	1.10	1.00	.90	.85		55
65	81				1.20	1.10	1.00	.92	.85	60
70	88					1.20	1.10	1.05	.95	67

Influence of Lysine Intake during Lactation on Subsequent Reproductive Performance

Once the optimal lysine level for litter weight gain has been determined, there still remains the question of sow longevity and the potential influence lactation feeding may have on subsequent reproduction. This question becomes critical when you consider that the lysine or protein requirement for optimal litter weight gain is lower than that required to minimize nitrogen loss and muscle catabolism during lactation. King et al. (1993) reported that first litter gilts nursing nine pigs required a 1.08% lysine diet (40.5 g/d) to maximize litter growth rate when feed consumption was 8.3 lb (Table 2). However, to minimize nitrogen loss, a 1.30% lysine diet (48.8 g/d) was required. These results are supported by Touchette et al. (1996) where they demonstrated the lysine requirement for minimizing weight loss (54 g/d) or loin muscle loss (58 g/d) were considerably higher than the amount needed to maximize litter weaning weights.

Table 2:

Effect of Dietary Lysine Intake During Lactation on First Parity Sows[a]

	Lysine, %					
Item	.44	.66	.87	1.08	1.30	1.51
ADFI, kg/d	3.8	3.7	3.8	3.8	3.8	3.6
Sow wt loss, kg	27.4	23.3	25.3	22.3	23.8	24.5
P1 Backfat loss, mm[b]	3.2	5.0	9.2	9.1	9.1	9.3
Litter growth rate, g/d[b,c]	177	191	213	227	213	218
Milk yield, kg/d						
Early lactation[d]	7.79	8.02	9.12	8.89	8.39	9.19
Late lactation[e]	7.02	7.40	8.42	8.40	7.76	8.90
Nitrogen Balance, g/d						
Early lactation[b]	-36.7	-26.2	-23.1	-13.9	-2.5	-6.7
Late lactation[b]	-25.9	-19.8	-16.1	-12.9	-.2	-6.7

[a]King et al., 1993
[b,d,e]Linear effect of lysine (P < .001; .05; .01, respectively).
[c]Quadratic effect of lysine (P < .05).

We must then ask ourselves the question of whether diets should be formulated to maximize litter weight gain or to minimize nitrogen loss by the sow. Until recently, evidence directly connecting amino acid intake during lactation and resultant muscle catabolism with reproductive hormone secretion or subsequent litter size was lacking. Research shown in Figure 2 by Tokach et al. (1992c) and data from Jones et al. (1994) demonstrate low amino acid and energy intake during lactation decreases LH secretion. King and Martin (1989) also found that sows experiencing restricted protein intake during lactation have a reduced mean LH concentration and fail to develop a high LH pulse frequency during lactation. Tokach et al. (1992c) also demonstrated that LH secretion during lactation was related to weaning-to-estrus interval.

Data from Australia has continued to clarify the connection between amino acid intake during lactation and subsequent reproduction. Tritton et al. (1993; as cited in King, 1994) reported that lysine intake during the first lactation period influenced subsequent litter size (Table 3). They found a 1.2 pig increase in the subsequent farrowing when gilts were fed a 1.30% lysine diet during their first lactation compared to diets with lower lysine levels. The optimal lysine level in this research coincides with the lysine level required to minimize negative nitrogen balance from King et al. (1993). This is an interesting finding that may provide insight into the second parity dip in litter size often seen in swine herds. A study comparing first parity sows fed dietary lysine levels of 0.9% or 1.3% supports the Australian data (Wilson et al., 1996). No differences were found between the treatments in litter weaning weight, but a shorter weaning to estrus interval was found for sows fed the higher lysine diet (15.0 days vs. 11.1 days).

In summary, research clearly demonstrates that amino acid

Table 3:

Influence of dietary lysine on lactation and subsequent reproductive performance in first-litter sows[a]

Item	Protein, %: Lysine, %:	14.9 .62	17.1 .84	19.5 1.06	22.5 1.31	24.9 1.51	SEM
Feed intake, kg/d		4.5	4.4	4.2	4.6	4.5	0.6
Lysine, g/d		28	37	45	61	68	- -
Pig weight on d 23, kg		5.7	6.3	6.1	6.7	6.2	0.4
Weaning to estrus, d		8.4	8.2	8.5	8.5	8.7	1.1
Subsequent litter size alive		9.7	9.5	9.8	10.9	10.6	0.5
Subsequent litter size total		10.3	9.8	10.4	11.6	11.0	0.5

[a]Adapted from Tritton et al., 1993 (as cited in King, 1994).

intake during lactation can influence subsequent reproduction. However, further research must be conducted to further characterize this relationship and to determine which amino acids are most important in this response. Three recent trials at the 1999 American Society of Animal Science meetings concluded that the lysine requirement for lactating sows was approximately 56 g/d. The problem with providing all sows in the herd with a specific level of lysine intake is the impact of parity on feed intake. An example of the distribution in parity and lysine intake for one farm is shown in Table 4. Only one lactation diet is practical on most farms. Thus, parity distribution should be evaluated to determine the most economical approach. Most farms in the U.S. slightly over-formulate the lactation diet for the older sows to more closely meet the requirements of the lower intakes in the first two parities.

Table 4:

Lactation Feed Intake and Lysine Intake as Influenced by Parity and Dietary Lysine Level

Item	Parity 1	2	3	4	5	6	7
Lactation feed intake, kg	4.6	5.2	6.1	5.9	6.4	6.2	6.5
Lysine intake, g/d							
.95% lysine diet	43.7	49.6	58.1	56.4	60.3	59.0	61.8
1.1% lysine diet	50.6	57.2	67.1	64.9	70.4	68.2	71.5

Other Amino Acids

Recent research have greatly improved our ability to provide a sow herd with the correct dietary lysine level for gestation and lactation. However, a question remains concerning the appropriate level for other amino acids in the diet. To help answer this question, information regarding the suggested amino acid ratios suggested by the NRC (1988 and 1998) and ARC (1981) for the lactating sow are listed in Table 5. Research with the other amino acids was summarized by Tokach et al. (1996). Briefly, researchers have demonstrated that the valine requirement (Tokach et al., 1992a, Richert et al. 1994a, b), total branch chain amino acid requirement (Richert et al., 1996), and methionine requirement (Schneider et al., 1992) are much higher than predicted by NRC or ARC. More research is needed with these amino acids, as well as, tryptophan and threonine; however, results to date indicate these amino acids must be carefully considered in diet formulation to prevent costly limitations during lactation. In practical diet formulation, we formulate to meet the lysine requirement of the sow and attempt to maintain valine, isoleucine, and methionine as high as possible without incurring excess cost. As more data becomes available these amino acids may be added as standard ingredients in lactation diets, similar to the use of synthetic amino acids in starter and grow-finish diets.

Table 5:

ARC and NRC Amino Acid Ratios for Lactating Sows[a,b]

Amino Acid	ARC Ratio[c]	NRC Ratio 1988	NRC Ratio 1998
Lysine	100	100	100
Histidine	39	42	39
Isoleucine	70	65	56
Leucine	115	80	108
Met & Cys	55	60	48
Phe & Tyr	115	117	111
Threonine	70	72	65
Tryptophan	19	20	18
Valine	70	100	82

[a]ARC (1981). [b]NRC (1988 and 1998).
[c]Amino acids are listed as a percent of lysine.

Gestation

Nutrient requirements during gestation can be divided into three different areas: 1) maintenance, 2) maternal growth, and 3) fetal growth. Basic energy and amino acid requirements can be determined using a factorial approach as will be demonstrated in the following sections. In addition, the pattern of intake is important due to influences on embryo survival, lactation feed intake, and, in recent literature, subsequent growth and lean deposition of the offspring.

Energy Requirements

Maintenance needs account for 75 to 80% of the energy requirement during gestation (Table 6). The maintenance energy requirement can be calculated as 0.46 MJ DE/kg$^{0.75}$. The requirement for maternal growth can be calculated by making assumptions about the composition of the gain and requirements to attain that composition (i.e. gain with a composition of 25% fat and 15% protein would have a requirement of approximately 20.9 MJ DE/kg gain). The developing litter has a very small nutrient requirement and a high priority for nutrients. The requirement for conceptus growth is only about 0.9 MJ DE/day. Using these values, you can easily calculate the energy requirement of sows in a thermoneutral environment. Approximately 50 g of feed is required for every degree celsius below 18°C (0.061 lb of feed for every degree fahrenheit below 64°F).

Excessive energy intake during gestation results in three major problems. The high energy (feed) intake: 1) is unnecessary expense; 2) reduces feed intake during lactation; and 3) impairs mammary development.

Amino Acid Requirements

Similar calculations to those for energy can be made to determine the requirement for protein (Table 7) or individual amino acids during gestation. Detailed estimates for the essential amino acids are provided by Pettigrew (1993). The individual amino acid requirements are influenced greatly by the expected lean tissue gain during pregnancy. A mature sow gaining 20 kg (44 lb) from breeding to farrowing requires less than 9 g/d of lysine, similar to NRC (1988) requirement. Younger gilts bred at 130 kg (285 lb) with an expected gain of 30 kg (66 lb) would require 11 g/d of lysine. As the expected weight gain increases, the lysine need may increase to as high as 14 g/d in some first parity gilts. However, these levels can be achieved with a relatively low lysine diet (0.55 to 0.70%), depending on the level of feed intake.

Excessive protein intake during gestation unnecessarily increases feed cost. In one trial (Mahan and Mangan, 1975), high protein intake during gestation reduced feed intake during lactation.

Table 6:

Energy Requirement of Gestating Sows.

Sow weight, kg	115	150	200
Weight gain, kg	30	20	10
		Mcal ME/day	
Maintenance	16.63	19.87	24.49
Weight gain	5.49	3.66	1.83
Conceptus	0.90	0.90	0.90
Total required	23.0	24.4	27.2
		Feed/day	
Kilograms	1.65	1.75	1.95

Assumptions: 14 MJ DE/kg diet.
Maintenance: .462 MJ DE/$kg^{.75}$ (.462 kcal(13 +.2 x live weight, kg)).
Weight gain: 20.9 MJ DE/kg gain (25% fat & 15% protein) x weight gain, kg / 114 days.
Conceptus: .9 MJ DE/day.

Sow in thermoneutral zone (50 g/d of feed required for each °C below 18 °C)

Table 7:

Protein Requirement of Gestating Sows.

Sow weight, kg	115	150	200
Weight gain, kg	30	20	10
		Protein, g/day	
Maintenance	60	79	105
Weight gain	39	26	13
Conceptus	21	21	21
Total required	121	126	139
Required in diet	216	225	248
		Feed/day	
Kilograms	1.60	1.67	1.84

Assumptions: 13.5% crude protein and .6% lysine in diet.
Dietary protein was 56% available (80% digestible and 70% biological value.
Maintenance, g/day : Sow weight, kg x .0525% protein *1000 g/kg.
Weight gain, g/day: 15% protein x weight gain, g / 114 days.
Conceptus gain: 20 kg at 12% protein = 2.4 kg; 2.4 kg/114 = 21 g/d.
Actual requirement is 13, 26, and 52 g/d in first, second and third trimesters.

Feed Intake Pattern During Gestation

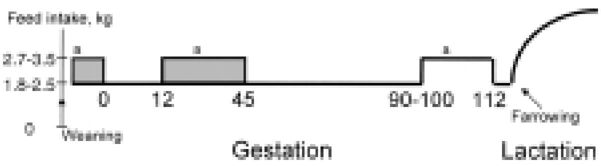
Energy and protein requirements during gestation were reviewed in the previous sections. High or low feed intake during particular phases during gestation can cause deleterious effects or have specific advantages. Each stage of gestation is discussed below. These stages are depicted in Figure 3 as a proposed ideal feeding pattern.

Day 0 to 30: Several researchers have reported high intake before day 30 of gestation decreased embryo survival. The increased embryo mortality was attributed to a reduction in plasma progesterone concentration due to increased blood flow and hepatic clearance of progesterone caused by the high feed intake. Further research (Jindal et al., 1996) indicates the critical window to reduce feed intake to prevent embryo mortality may be during the first 48 to 72 hours after mating. The safest recommendation is to limit feed intake from breeding until day 12 after breeding.

The body condition or energy state of the sow also influences the response to high levels of feed intake after mating. Embryo mortality is only increased when high levels of feed are provided to sows in good body condition. Embryo mortality was actually reduced by providing extra feed for the first thirty days after breeding to sows in poor body condition due to low lactation feed intake. Therefore, feeding according to body condition during the first 30 days of gestation is critical for minimizing embryo mortality. Recent unpublished data from Australia also credits high feeding during early gestation with increasing farrowing rate during the summer months when seasonal infertility is a problem.

Feeding level from day 0 to 45 is shown as a shaded area in Figure 3. The shading indicates the feeding level should be adjusted to match the body condition of the sow. The goal should be to have the sow at the body condition desired for farrowing by day 45 of gestation. In order to reduce the possibility that the higher feed intake will increase embryo mortality, feeding level from day 0 to 12 of gestation is shown at the baseline value (approximately 2 kg (4.4 lb) of a diet containing 3.2 Mcal ME). Remember, very thin sows should receive a high level of intake immediately after mating until body condition is restored.

Figure 3:



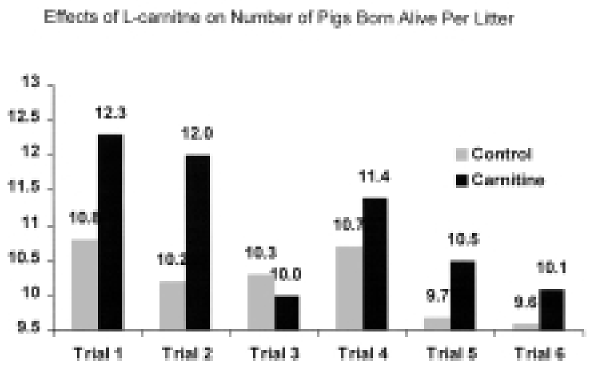
Gestation feed intake pattern.

Day 30 to 75: Current understanding of this period during gestation is poor. As shown in Figure 3, the general recommendation is to feed a constant level sufficient to meet the energy requirements of the sow and maintain body condition. However, recent research indicates this is a critical period for muscle differentiation of the developing fetuses. Sterle et al. (1995) found injections of porcine somatotropin (pST) between day 30 and 43 increased placental weight and weight of the lightest fetuses. The authors hypothesized that pST increased nutrient uptake and utilization by the fetuses by increasing nutrient transfer across the placenta. In another trial, pST injections from day 28 to 40 increased embryo survival, embryo weight, and specific gene expression for certain muscles (Kelly et al., 1995). Offspring from the sows injected with pST for the specific window of gestation (day 28 to 40) had reduced backfat and heavier trimmed loin weight at market than pigs from the control sows. Dwyer et al. (1994) observed a similar response by doubling feed intake (2.5 vs. 5.0 kg/day) from day 25 to 80 of gestation. The high feed intake increased the number of secondary muscle fibers and improved growth rate and feed efficiency of the offspring during the growing period (day 70 to 130 of age). As subsequent research identifies the specific nutrient(s) and time period to elicit the optimal response, stage feeding during gestation for muscle development of the fetuses may become an important part of commercial swine production.

Carnitine is a water soluble, vitamin-like compound which primarily functions to transport fatty acids across the mitochondria membrane where they are processed to produce energy. L-carnitine has also been shown to affect several key enzymes involved in protein and lipid metabolism. Gestating sows are generally fed once daily. Research at Louisiana State University shows that fasted growing-finishing pigs have higher concentrations of free fatty acids (FFAs) approximately 8 hours after eating. At about the same time there is a decrease in glucose in the blood, due in part to depleting body glycogen reserves. Therefore adding L-carnitine to the gestation diet might assist in the utilization of FFA for energy, due to increased beta-oxidation, and glucose supply might be enhanced due to improved gluconeogenesis. Juvenile atlantic salmon supplemented with L-carnitine have increased gluconeogenesis and increased production of acyl Co-A resulting from improved beta-oxidation. If this improvement in nutritional status occurs in gestating sows, then increases in Insulin-Like Growth Factor-I (IGF-I) and other myogenic factors might occur due to changes in blood glucose and possibly enhanced myogenesis in the fetal pigs.

We have conducted six experiments evaluating added L-carnitine fed during gestation and (or) lactation. With the exception of Exp. 2, no differences in litter weaning weights have been observed when L-carnitine has been fed compared with control sows. However, in five out of the six experiments, increases in subsequent litter size have been observed in sows fed L-carnitine in gestation and(or) lactation. The range in increased number of pigs born alive ranged from 0 to 1.8 and averaged between 0.7 and 0.9 pigs per litter (Figure 4).

Figure 4:



In addition to the effects of L-carnitine on the number of pigs born live, we have also observed increases in insulin and IGF-I concentrations of sows (Musser, 1999). Increased IGF-I during specific windows of gestation (days 30 to 50) has been associated with changes in fetal muscle fiber development resulting in leaner, faster growing offspring. Results for initial field studies appear to confirm this possibility in pigs raised from sows fed L-carnitine during gestation (Musser, 1999). In one study, finishing pigs from sows fed 50 ppm of L-carnitine during gestation had an increase in percentage lean compared with pigs from control sows (53.4 vs 51.9%, respectively). In a second study, percentage lean was increased by 0.64 of a percentage unit. Further research is needed to confirm this effect on fetal muscle fiber development from feeding L-carnitine during gestation.

Day 75 to 100: This period is critical for mammary development. Excessive energy intake during this period increases fat deposits and reduces the number of secretory cells, DNA, and RNA in the mammary gland (Weldon et al., 1991). The result is lower milk production during lactation. Excess feed intake should be avoided during this time.

Day 100 to 112: Feed intake should be increased by 1 to 2 kg (2 to 4 lb) from day 100 to 112 of gestation to prevent sows from losing weight during this period of rapid fetal growth. Failure to increase feed intake during this period results in sows in an extremely catabolic state at farrowing. The catabolic state contributes to gorging and sows „going off feed“ during lactation.

Day 112 to 114: Feeding pattern during the last few days of gestation is a controversial area. We prefer to feed 2 kg or more from day 112 to 114. Field experience indicates that extremely low intake of 1 kg or less during this time limits the producers ability to increase feed intake rapidly during early lactation. In extreme cases, ulcers can be created by the extended period of low intake around farrowing. After the long period without feed, sows often overeat if provided free access to feed. The sows will go off feed or have a noticeable dip in feed intake. Many people prescribe limit feeding as a cure for the sows going off feed instead of correcting the problem that originally caused the problem (the extended period of little or no feed intake prior to and immediately after farrowing).

Conclusion

Productivity and lactation feed intake are important determinants for optimizing diet formulations for lactating sows. Diets for lactating sows should be formulated to match the level of feed intake and sow productivity (litter weaning weight). Formulating higher protein diets for first and second parity sows minimizes nitrogen loss and improves subsequent reproductive performance. When formulating diets for lactating sows, care should be taken to avoid deficiencies in amino acids other than lysine (valine, isoleucine, methionine). Nutrient requirements during gestation are small, but the feed intake pattern can influence reproductive performance. Staged feeding is important to meet the specific goals of each period during gestation. Timing as well as quantity of nutrients fed during each gestation period is important for optimizing subsequent lactating and reproductive performance.

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