Applying New Research to Reduce Sow Feed Costs

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▪ Take Home Message

There is potential to significantly reduce the cost of sow feeding, however, current nutrient recommendations need improvement. Phase feeding, using separate diets for early/mid gestation and late gestation, may save up to $5.00 per sow per gestation. Using a single diet for gestation, but phase feeding at a higher level in late gestation, may save up to $3.00 per sow per gestation. During late gestation and lactation, addition of free amino acids can reduce feed cost. These improvements may also increase sow productivity and increase sow longevity.

▪ Introduction

Nutrition of sows has received little attention compared to growing-finishing pigs, despite the fact that sows consume approximately 20% of the all the feed consumed in pork production. Therefore, improving sow nutrition offers the opportunity for substantial savings in feed cost. This paper will review recent research, discuss future opportunities in sow nutrition, suggest new feeding strategies for sows, and estimate their impact on feed cost.

▪ Gestation Feeding

Current recommendations for nutrient and energy intake during gestation are constant (NRC 1998). However, practical experience (Jackson 2009) has shown that feed and nutrient intake must be increased during late gestation to maintain performance and sow longevity. Unfortunately, there is very little objective data on the optimum nutrient balance for late gestation feeding.

Factors determining nutrient and energy requirements during gestation are: sow body weight, target maternal gain during gestation, and conceptus gain, which is driven by litter size (NRC 1998). Conceptus gain increases rapidly after day 68 of gestation (McPherson et al. 2004) and has a greater priority for nutrient supply than maternal gain. However, maternal body weight gain is necessary for sows to cope with the following lactation and should comprise both protein and lipid gain (Whittemore and Morgan 1990). Because lipid gain has a lower priority than protein gain, the energy and amino acid requirements for maternal maintenance, conceptus growth and maternal protein gain must be met before the sow will deposit lipid. Therefore, practical recommendations are often to increase nutrient and energy allowance in late gestation to allow sows to maintain and improve their body condition prior to farrowing. Ignoring these dynamics by applying a single phase feeding program will lead to overfeeding during early gestation and underfeeding during late gestation. Overfeeding in early gestation results in a waste of feed and money, while underfeeding in late gestation leads to sows entering lactation in a severe catabolic state.

■ Amino Acid Requirements for Sows

A group from Germany has recently published new recommendations for swine nutrition (GfE 2008). These recommendations suggest that amino acid requirements in late gestation are greater than in early gestation. However, in the absence of supporting experimental data, requirements were calculated from the estimated increased growth of conceptus products in late gestation. GfE (2008) proposed a change of diets on day 85 of gestation to accommodate the greater amino acid requirement caused by increased fetal growth. For example, GfE (2008) suggested standardized ileal digestible lysine intake of 9.4 g/d for day 1 to 85 of gestation and 14.6 g/d for day 85 to 115 (Table 1). The corresponding calculated values for threonine, based on estimated amino acid ratios for sow maintenance and body protein growth, are 6.6 g/d and 9.6 g/d (**Table 1**). Although we agree with the concepts used to derive these recommendations, these requirement estimates should be treated with caution until they are confirmed with experimental data.

We recently measured the threonine requirements of gestating sows by indicator amino acid oxidation and plasma concentrations (Levesque et al. 2009); we found that in early gestation (day 35 to 53) sows required 6.1 and 7.2 g/d and during late gestation (day 92 to 110) required 13.6 and 14.0 g/d, respectively. At mid-gestation (day 63 to 70), the requirement by indicator oxidation was 7.0 g/d. Our estimates for early and mid-gestation are similar to those of GfE (2008) but are markedly lower than NRC (1998) (Table 1). However, the threonine intake required for maximum protein synthesis in late gestation is more than double that required during early gestation, and considerably exceeds the recommendation of both NRC (1998) and GfE (2008). The comparison shown in Table 1 also illustrates that a large degree of uncertainty exists in the magnitude of amino acid requirements and the optimal ratios among the amino acids.

Table 1. Comparison of true ileal lysine and threonine requirements of gestating sows according to GfE (2008), NRC (1998) and Levesque et al. (2009)

	NRC[1] (1998)		GfE[1] (2008)		Levesque et al. (2009)	
	Lysine	Threonine	Lysine	Threonine	Threonine (IAAO[2])	Threonine (PAA[3])
Early gestation, g/d (day 1 to 85)	10.6	8.5	9.4	6.6	7.0	7.2
Late gestation, g/d (day 85 to 115)	10.6	8.5	14.6	9.6	13.6	14.0
Mean for gestation, g/d	10.6	8.5	10.8	7.4	8.7	9.0

[1]based on second parity sows: 185 kg body weight, expected litter size: 13 piglets, average feed intake 2.45 kg/d of a corn-soy equivalent diet (13.8 MJ ME/kg)

[2] IAAO, Indicator amino acid oxidation

[3] PAA, Plasma amino acid concentration

The recommendations of the GfE (2008) do not include an allowance for the nutrients needed to regain body tissues lost in a previous lactation. GfE (2008) suggested to increase the true ileal digestible lysine and threonine intake by 1.5 g/d and 0.9 g/d, respectively, throughout lactation for each 10 kg of body weight lost during the preceding lactation. In comparison, the ‘real life’ results of Levesque et al (2009) were determined in sows that lost, on average, 6.3 kg during the preceding lactation. Based upon the GfE (2008) estimate that requirement increases by 0.9 g/d of threonine per 10 kg lost in a preceding lactation, regaining this weight loss would therefore increase the threonine requirement of the sows used by Levesque et al. (2009) by 0.6 g/d, compared to sows that didn’t lose weight. Therefore, the requirement estimated by

Levesque et al. (2009) probably reflects the need for increased threonine for regaining body tissue, as calculated by GfE (2008).

Dietary Amino Acid Availability for Sows

Nearly all the data on digestibility of dietary amino acids have been obtained from research with growing-finishing pigs; there are very few data for sows, despite the fact that age or body weight has long been recognized as a factor influencing protein and energy digestibility (Ball and Aherne 1987, CSIRO 1987). Stein et al. (2001) found that the standardized ileal digestibility of lysine and threonine in corn and soybean meal was significantly greater for gestating sows than for growing pigs.

Despite this evidence, the same standardized amino acid digestibilities are currently used for pigs of all ages. The correct digestibility values for gestating sows will lead to cheaper gestating diets and must be known to accurately formulate diets using our new requirement values. For example, if the amino acid digestibility of common ingredients is about 5% greater for sows than for growing-finishing pigs this would reduce diet cost by approximately $1.00/tonne.

Energy Requirements During Gestation and Lactation

Similar to amino acids, energy requirement during gestation can be expected to increase as pregnancy progresses, predominantly because of the exponential growth of fetuses. If not given sufficient energy, sows develop insulin resistance, which reduces nutrient uptake by the maternal body and thus diverts nutrients to the products of conceptus. This was illustrated by the recent work of Bikker et al. (2007) who showed that sows given a constant feed allowance during pregnancy developed insulin resistance in late gestation, whereas sows given a supplement of 540 g/d starch in late gestation did not. This clearly shows that insulin resistance in late gestation is a response to inadequate energy intake. The amount of starch supplement used by Bikker et al. (2007) would provide approximately 9 MJ ME/d, which is similar to the estimate of GfE (2008); that energy requirements increase by 6 – 8 MJ ME/d in the last trimester of pregnancy.

We recently found (Samuel et al. 2008a) that 2nd parity sows increased their daily heat production by 4.0 MJ on day 105 vs. day 30 and 45 of gestation. Due to the increased weight of the sows, 1.5 MJ of energy were required for maintenance, and 2.5 MJ of heat were produced as a result of maternal and fetal tissue gain. Applying an assumed efficiency of energy retention of 0.70 (ARC 1981) results in an increased dietary energy requirement of 7.5 MJ

ME/d during late gestation. When added to the estimated maintenance requirements (507 kJ/kg$^{0.75}$, Samuel et al 2007), this value can be used to calculate daily energy requirements, as shown in **Table 2** and compared to NRC (1998) and GfE (2008) recommendations.

Table 2. Estimated energy requirements[1] of gestating sows according to NRC (1998), GfE (2008) and Samuel et al. (2008a,b).

	NRC (1998)		GfE (2008)		Samuel et al. (2008a,b)	
	MJ ME/d	Feed, kg/d[2]	MJ ME/d	Feed, kg/d[2]	MJ ME/d[3]	Feed, kg/d[2]
Early gestation (day 1 to 85)	36.2	2.63	32.0	2.32	31.0	2.25
Late gestation, (day 85 to 115)	36.2	2.63	40.0	2.90	38.5	2.79
Mean for gestation,	36.2	2.63	33.8	2.45	33.0	2.39

[1]based on second parity sow: 185 kg body weight at service, expected litter size: 13 piglets, 40 kg maternal gain

[2]corn-soy diet (13.8 MJ ME/kg)

[3]calculated as (heat production – maintenance energy)/0.3 + maintenance energy. Maintenance energy was estimated as 507 kJ/kg$^{0.75}$ maternal body weight, 0.3 denotes the heat associated with energy deposition (1 – efficiency of energy utilization of 0.70)

These comparisons, in the bottom live of Table 2, show that a greater total amount of feed is needed according to NRC (1998) compared to Samuel et al, (2008a,b) and GfE (2008) because of the unnecessary overfeeding in early and mid gestation. Feeding according to NRC (1998) results in the excess nutrient intake being deposited as body fat and protein, and then mobilized in late gestation when energy and protein intake is insufficient. It is energetically inefficient to deposit fat and protein and then later mobilize it. For example, the efficiency of depositing feed energy as fat is only 74% and the efficiency of utilizing body fat for energy is only 90%; therefore, energy is lost twice – once during deposition of body tissues, and again during their mobilization. Feeding sows according to their changing energy needs in gestation can save at least 20 kg of feed per sow per gestation, or $5.00 at a diet cost of $250/tonne. Assuming 2.5 gestation cycles per year – this is a saving of $12.50 per sow per year.

A further benefit of increased feed allowance during late gestation is to reduce backfat loss during lactation (Miller et al. 2000). Therefore, increasing the feed allowance in late gestation may reduce the need for additional feed in the next pregnancy, or allow the sow to produce more milk during lactation.

▪ Dietary Net Energy for Sows

NE in feedstuffs and complete diets is predicted using the content of digestible nutrients. However, nutrient digestibility is higher for sows than for growing pigs. Because there is little research on net energy digestibility in feedstuffs, Noblet et al. (2003) proposed correction factors, differing among feedstuffs, to extrapolate NE for sows from the NE for growing-finishing pigs. These correction factors are between 1 and 5% and result in greater NE values for sows compared to growing pigs.

Better NE data is needed for sows because we will be better able to match feed intake with the desired energy deposition in the sow's body and conceptus during gestation. We predict that this will allow a reduction in feed allowance of 2% relative and will amount to approximately 5 kg during gestation, or $1.25 per sow at a cost of $250/tonne.

A benefit of using the NE system for growing pigs is that diet costs are generally reduced due to greater inclusion rates of energy feeds compared to protein feeds. The reduced contribution of protein feeds to amino acid supply is addressed by inclusion of free amino acids for growing pigs. Because sows are typically fed only once daily, it may be questioned whether added free amino acids are fully utilized. In growing-finishing pigs (Batterham and Murrison 1990), the utilization of free amino acids was reduced with infrequent feeding. Our studies (Möhn et al. 2002) showed no negative effect on sow gestation performance for 2 cycles when sows were fed reduced protein diets containing 2.8 g/kg free lysine and 1.2 g/kg free threonine. Although this low-protein diet tended to be cheaper than the conventional diet, it contained excess amino acids during early gestation and thus did not convey the full monetary benefit of protein reduction. Srichana et al. (2007) included 0.2% L-lysine-HCl in diets for gestating sows and found similar N-retention in sows fed once or twice daily. Although the utilization of free amino acids in gestating sow diets needs further investigation, these recent data suggest that free amino acids are utilized to a high degree by gestating sows.

▪ Nutrient Requirements and Sow Age

As sows approach maturity, their maternal growth rate diminishes. The deceasing component of maternal growth in gestating sows can be expected to lower amino acid requirements, and to a lesser degree, energy requirements. This will predominantly affect early and mid gestation requirements, because in late gestation the component of conceptus growth will contribute to requirements to a similar degree as in younger, smaller sows. This is demonstrated by the recommendations of GfE (2008) which show a dramatic decrease in amino acid requirements with increasing parity with the recommended daily TID lysine intake being as low as 3.7 g/d for sows in the 4^{th} parity, compared to 9.4 g/d in the second parity.

This lysine requirement could be met by 100% grain diets without addition of any protein feeds (Möhn et al 2002). This offers the opportunity for substantial feed cost savings. However, it should be noted that lysine probably is not the first-limiting amino acid for older sows that are at maintenance; threonine and possibly methionine and cystine are more likely to be first limiting, and diet formulation should be governed by the contents of these amino acids.

A final consideration is that sows lose body reserves of minerals over several reproductive cycles. The mineral loss reported by Mahan and Newton (1995) was most severe in sows supporting a high litter growth rate, and amounted to about 20% of body calcium over 3 parities. More research is necessary in sows specifying if, or how much additional mineral supplementation may be beneficial.

▪ Lactation Feeding

More accurate composition of lactation diets has the potential to both increase milk production and to better maintain body condition during lactation. Lactating sows, in most cases, lose weight during lactation because they cannot achieve the feed intake needed to supply the nutrients to meet their requirements for both milk production and maintenance. Milk production has a higher priority for nutrients than does maintenance of the sow's body tissues. Increases in nutrient intake during lactation are almost completely reflected in increased milk yield – and thus weaning weight of piglets.

Consequently, lactating sows need ad-libitum access to high-energy and high protein diets. However, the most efficient use of dietary energy and protein occurs when both nutrients are at optimum levels (Ball et al., 2008). Obviously, if either nutrient is deficient, feed intake and milk production will not be maximized and the sow will try to use her body stores to make up the deficiency. However, if the sow is fed excess protein, or protein is that not perfectly balanced in amino acids, the sow will also eat less feed and will be less efficient at using dietary energy. She will both produce less milk and will lose more body fat stores compared to receiving a diet with the optimum balance of amino acids.

Optimizing amino acid balance in lactation diets will require more supplementation with free amino acids. Johnston et al. (1999) found no detrimental effect of diets with 0.22% added L-lysine-HCl, while McMillan et al. (2002) reported reduced sow feed intake and piglet performance for diets with added 0.36% L-lysine-HCl and 0.13% L-threonine. Srichana et al. (2007b) and Renaudeau et al. (2001) reported no negative effect of the inclusion of 0.3 % and 0.55% free L-lysine-HCl in lactation diets, respectively. However, the diets used by Srichana et al. (2007b) and Renaudeau et al. (2001) were supplemented, regardless of cost, with several amino acids that were potentially limiting. These differences in response to inclusion of free amino acids in lactating sow diets are probably due to lack of knowledge of amino acid requirements; further research is needed to determine the optimum levels of free amino acids that can be used in commercial lactation diets.

▪ A New Sow Feeding Program

The above information has been used to develop a revised feeding program for gestating sows:

- Lower energy and lower protein intake for early gestation from day 1 to 84
- Higher energy and higher protein diet for late gestation from day 85 to 112

Applying these strategies to the example sows used in Tables 1 and 2 allows calculation of their impact on feed cost. Compared to the reference diets in **Tables 3 and 4**, which were formulated to meet NRC (1998) requirements, imposing a phase feeding strategy reduced feed cost/sow for both corn- and barley-based diets. For both types of diet, the phase feeding strategies lead to reduced diet cost and feed allowance in early and mid gestation, but increased feed allowance and feed cost in late gestation. The potential savings are predominantly due to the reduced overall feed usage by phase feeding in the first two trimesters of pregnancy. Although offset by greater feed cost in late gestation, phase feeding can still be expected to save as much as $5.00 per sow per gestation.

Both phase feeding programs (Tables 3 and 4) show that different diets are necessary to fulfill amino acid requirements with the target energy (feed) intake. This is a limitation for the commercial implementation of a phase-feeding program, because most barns have a single feed delivery system. If a single diet is used for both phases, this diet needs to cover the higher amino acid requirement in late gestation. Consequently, amino acid supply in early and mid gestation will exceed requirements and impose additional diet cost. However, because of the reduced feed allowance needed up to day 84 of gestation, phase feeding with a single diet may still save $2 to $3 compared to feeding according to the NRC (1998) recommendations.

Note that the estimated lysine requirement differs by up to 25% among feeding programs. This is a reflection of the current uncertainty about amino acid requirements during gestation. The lysine requirements shown in Tables 3 and 4 were estimated using a ratio of lysine:threonine of 1:0.75. Lysine requirements during early and late gestation must be determined empirically because the present research indicates that the differences in amino acid requirements are much larger than have previously been predicted (anonymous, 2008). Additional research on all the key amino acids is needed to derive more accurate requirement values if we are to devise feeding regimens closer in agreement with actual needs of the sow.

Table 3: Corn-soybean meal diets[1] for gestating sows[2] formulated to fulfill NRC (1998), GfE (2008) or our own recommendations

	NRC (1998)	GfE (2008)		Ball (2009)	
		Day 1 - 84	Day 85 - 112	Day 1 - 84	Day 85 - 112
Feed, kg/d	2.63	2.32	2.90	2.25	2.79
TID lysine, %	0.45	0.35	0.50	0.35[3]	0.55
TID threonine, %	0.34	0.28	0.29	0.26	0.41
Diet:					
Corn, %	84.7	86.5	82.5	89.2	80.1
Soybean meal, %	11.3	9.5	13.5	6.8	15.9
Minerals & vitamins, %	4.0	4.0	4.0	4.0	4.0
Diet cost, $/tonne	236.91	233.85	240.98	228.58	245.42
Feed cost, $	69.78	46.12	18.87	43.72	18.49
Total feed cost, $ per gestation	69.78	64.98		62.20	

[1]Metabolizable energy 13.8 MJ/kg. Main ingredient cost based on $225.00/tonne corn and $410.00/tonne soybean meal (Unifeed, Lethbridge, Nov 24, 2008)

[2]Sow of 185 kg body weight, 40 kg maternal gain, expected litter size: 13 piglets

[3]Based on determined threonine requirement, assuming a lysine : threonine ratio of 1:0.75 (after NRC 1998)

Table 4: Barley-canola meal[1] diets for gestating sows[2] formulated to fulfill NRC (1998), GfE (2008) or our own recommendations

	NRC (1998)	GfE (2008)		Ball (2009)	
		Day 1 - 84	Day 85 - 112	Day 1 - 84	Day 85 - 112
Feed, kg/d	3.05	2.69	3.36	2.59	3.21
TID lysine, %	0.39	0.35	0.43	0.31[3]	0.48
TID threonine, %	0.30	0.25	0.29	0.23	0.36
<u>Diet</u>:					
Barley, %	85..5	89.0	82.3	92.3	78.0
Canola meal, %	9.5	6.0	12.7	2.7	17.0
Canola oil, %	1.0	1.0	1.0	1.0	1.0
Minerals & vitamins, %	4.0	4.0	4.0	4.0	4.0
Diet cost, $/tonne	184.70	184.20	185.54	183.54	186.40
Feed cost, $	63.09	42.12	16.83	40.41	16.16
Total feed cost, $ per gestation	63.09	58.95		56.56	

[1]Metabolizable energy 12.0 MJ/kg. Main ingredient cost based on $180.00/tonne barley and $200.00/tonne canola meal (Unifeed, Lethbridge, Nov 24, 2008)

[2]Sow of 185 kg body weight, 40 kg maternal gain, expected litter size: 13 piglets

[3]Based on determined threonine requirement, assuming a lysine : Threonine ratio of 1:0.75 (after NRC 1998)

■ Conclusions

There is a great deal more to be learned about energy and amino acid requirements during different phases of gestation and lactation. As this information becomes available, we expect to further reduce the cost of sow feeding while maintaining or increasing sow productivity and longevity.

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▪ References

Agricultural Research Council (ARC). 1981. The Nutrient requirements of pigs Slough: Commonwealth Agricultural Bureau.

Anonymous. 2008. SID Lysine requirements of gilts during different stages of gestation and the impact of synthetic amino acids on nitrogen retention. Ajinomoto Heartland LLC Swine Research Report #46.

Ball, R.O. and F.X. Aherne. 1987. Influence of dietary nutrient density, level of feed intake and weaning age on young pigs. 2. Apparent nutrient digestibility and incidence and severity of diarrhea. Can. J. Anim. Sci. 67: 1105-1115.

Ball, R.O., R.S. Samuel and S. Moehn. 2008. Nutrient Requirements of Prolific Sows. Advances in Pork Production 19:223-236.

Batterham, E. S. and R. D. Murison. 1981. Utilization of free lysine by growing pigs. Br. J. Nutr. 46:87-92.

Bikker, P., J. Fledderus, J. Kluess and MJH Geelen. 2007. Glucose tolerance in pregnant sows and liver glycogen in neonatal piglets is influenced by diet composition in gestation. EAAP Publication No. 124:203-204.

CSIRO. 1987. Feeding Standards for Australian Livestock. Pigs. CSIRO Australia: East Melbourne.

GfE (2008). Recommendations for the supply of energy and nutrients to pigs. DLG Verlags GmbH, Frankfurt, Germany.

Jackson, A.S. 2009. Practical control of sow feed costs. Advances in Pork Production, Volume 20: .

Johnston. L.J. M.Ellis, G.W. Libal, V.B. Mayrose, W.C. Weldon, and NRC-89 Committee on Swine Management. 1999. Effect of room temperature and dietary amino acid concentration on performance of lactating sows. J. Anim. Sci. 77:1638-1644.

Levesque, C.L., S. Moehn and R.O. Ball. 2009. Threonine requirement of sows in early, mid- and late gestation. Advances in Pork Production, Volume 20, Abstr. 2.

Mahan, D.C. and E.A. Newton. 1995. Effect of initial breeding weight on macro- and micromineral composition over a three-parity period using a high-producing sow genotype. J. Anim. Sci. 73: 151-156.

McMillan, D.J., S. Möhn and R. O. Ball. 2002. Low protein diets can be fed to lactating sows with few adverse effects. Joint ASAS, ASDA, CSAS 2002 National Meeting, Quebec City, QC, July 20—25, 2002, J. Anim. Sci. 80, Suppl.1, 14.

McPherson, R.L., F. Ji, G. Wu, J.R. Blanton, Jr. and S.W. Kim. 2004. Growth and compositional changes of fetal tissues in pigs. J Anim Sci 82:2534-2540.

Miller, H.M., G.R. Foxcroft and F.X. Aherne. 2000. Increasing food intake in late gestation improved sow condition throughout lactation but did not affect piglet viability or growth rate. Anim. Sci. 71:141-148.

Möhn. S., D. J. McMillan and R. O. Ball, 2002. Low protein diets can be fed to gestating sows without adverse effects. ASAS, ASDA, CSAS 2002 National Meeting, Quebec City, QC, July 20—25, 2002, J. Anim. Sci. 80, Suppl.1, 130.

Noblet, J, Bontems, V. and Tran, G. 2003. Estimation de la valeur energetique des aliments pour le porc.INRA Prod. Anim. 16:197-210.

NRC. 1998. Nutrient Requirements of Swine (10th Ed.). National Academy Press. Washington, DC.

Renaudeau, D., N. Quiniou, and J. Noblet. 2001. Effects of exposure to high ambient temperature and dietary protein level on performance of multiparous sows. J. Anim. Sci. 79:1240-1249.

Samuel, R.S., S. Moehn, L.J. Wykes, P.B. Pencharz and R.O. Ball 2007. Feeding frequency alters protein and energy metabolism of sows fed 1 x and 2 x the energy requirement for maintenance. . EAAP Publication No. 124: 501-502.

Samuel, R.S., S. Moehn, L.J. Wykes, P.B. Pencharz and R.O. Ball. 2008a. Late gestation energy intake is inadequate in modern, high productivity sows. Western Nutrition Congresss, Edmonton, AB

Samuel, R.S., S. Moehn, P.B. Pencharz and R.O. Ball. 2008b. Dietary lysine requirement for maintenance is 49 mg/kg$^{0.75}$ in a population of modern, high productivity sows. Advances in Pork Production, Volume 19, Abstract #1.

Srichana, P., A.M. Gaines, J.L. Usry, R D. Boyd and G.L. Allee. 2007a. Evaluation of crystalline amino acid supplementation and feeding frequency in gestating sows. J. Anim. Sci. 85(Suppl. 2): 98. (Abstr.)

Srichana, P., J.L. Usry, C.D. Knight, L. Greiner, & G.L. Allee. 2007b. The use of crystalline amino acids in lactating primiparous sow diets. J. Anim. Sci. 85 (Suppl. 2): 100. (Abstr.)

Stein, H.H., S.W. Kim, T.T. Nielsen and R. A. Easter. 2001. Standardized ileal protein and amino acid digestibility by growing pigs and sows J. Anim. Sci. 79:2113–2122.

Whittemore, C.T. and C.A. Morgan. 1990. Model components for the determination of energy and protein requirements for breeding sows: a review. Livest. Prod. Sci. 26: 1-37.