Phase feeding for pregnant sows

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Take Home Message

Parity-segregated phase feeding of pregnant sows supplies the amino acids and energy necessary to match the sows' requirements. This can result in reduced feed cost, better sow condition at farrowing, better rebreeding success and prolonged productive life of sows.

Introduction

In the last few years, our new research in sow nutrition has provided evidence that the traditional feeding regimen of gestating sows needs revision. In particular, the change of amino acid requirements from early to late gestation and the energy deficit of young sows in late gestation indicate that phase feeding of pregnant sows may be advantageous. This paper will review recent sow nutrition research and suggest feeding strategies for sows.

Gestation Feeding

Genetic improvement in lean yield and reproductive parameters such as litter size (CCSI, 2007) indicate that the amino acid requirements for sows should be re-evaluated.

Currently, NRC (1998) recommends for constant nutrient and energy allowances during gestation. However, practical experience (Jackson, 2009) has shown that feed and nutrient intake must be increased during late gestation to maintain performance and sow longevity. Constant values for amino acid and energy requirements during gestation assume an equal distribution of nutrient demand throughout gestation. However, the metabolic focus of the sow changes from the recovery of sow body tissue following weaning to the synthesis of fetal tissue in late gestation (McPherson et al., 2004). Fetal weight, fetal protein content and mammary protein content increase 5-, 18- and 27-fold, respectively, in the last 45 d of gestation (McPherson et al., 2004; Ji et al., 2006). These dramatic increases in fetal weight and protein gain indicate that the requirement for amino acids must be greater in late gestation compared to early gestation. 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

Based on these physiological changes, amino acid requirements of pregnant sows were modeled by Kim et al. (2009) and a group from Germany (GfE 2008). Although the recommended levels of amino acid intake differ between these authors, they agree that amino acid requirements in late gestation are greater than in early 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 true 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 in 2^{nd} parity sows. The corresponding 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. 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.

Experimental data from our research group cover the requirements in early and late gestation for lysine (Samuel et al., 2010), threonine (Levesque et al., 2011a), isoleucine and tryptophan (Moehn et al., 2012 a,b). In these experiments, each sow received each of six test diets in both early and late gestation. Feed allowance was kept constant throughout gestation. Amino acid requirements were determined using the indicator amino acid oxidation technique simultaneously with indirect calorimetry to measure energy expenditure. Key parameters of these experiments are compiled in **Table 1**. Few other amino acid requirement studies of pregnant sows were performed in the last 10 years. Srichana (2006) used the nitrogen balance technique to determine the lysine requirement of gilts in early, mid and late pregnancy. Zhong et al. (2009) reported the true ileal digestible lysine requirement in gilts up to day 84 of pregnancy as 0.69% in a diet containing 12.5 MJ ME. Dourmad and Etienne (2002) did not report differences in lysine and threonine requirements in four consecutive nitrogen balance periods in pregnant sows.

Srichana (2006) found no difference in the lysine requirement of 15.0 g/d between early and mid gestation, but reported an increased requirement of 18.0 g/d in late gestation (**Table 2**). Samuel et al. (2010) showed that the lysine requirement of 2^{nd} parity sows was 13.1 g/d and 18.7 g/d in early and late gestation, respectively. For 3^{rd} parity sows, the dietary total lysine requirement was 8.2 g/d and 13.0 g/d for early and late gestation, respectively (Samuel et al., 2010). Levesque et al. (2011a) found that second parity sows required 7.2 g/d total threonine in early gestation (day 35 to 53) and 13.6 g/d threonine in late gestation (day 92 to 110), based on indicator amino acid oxidation. In multiparous sows (Levesque et al., 2011a), the total threonine requirement was more than doubled from 5.0 g/d in early gestation to 12.3 g/d in the last third of gestation. The tryptophan requirement of 2^{nd} parity sows increased from 1.7 g/d to 2.6 g/d from early to late gestation. The isoleucine requirement of 4^{th} parity sows increased from 3.6 g/d to 9.6 g/d from early to late gestation.

These requirement values need to be considered with respect to sow performance as affected by stage of gestation and age of sows. Total nutrient requirements of pregnant sows are comprised of the requirement for maintenance plus the requirements for maternal and fetal growth. The body weight of sows increased from early to late gestation (**Table 3**), regardless of parity, and increased from parity 2 to 4. Protein deposition was greater in late than early gestation, regardless of parity. Litter size and weight changed marginally over 3 parities. Fetal growth occurs predominantly in late gestation (McPherson et al., 2004); this is reflected by the increase in protein deposition from early to late gestation in all three parities. Thus, fetal growth contributes more to amino acid requirements in late gestation, while maintenance and maternal growth are the principal factors for amino acid requirements in early gestation. Because maternal growth markedly diminished in the 4^{th} compared to 2^{nd} and 3^{rd} parity, older (adult) sows will require amino acids in early gestation predominantly for maintenance. In fact, the isoleucine requirement for maintenance in early gestation (2.2 g/d based on 35 $mg/kg^{0.75}$ body weight, Moehn et al. 2012c) was only slightly less than the measured early gestation requirement of 3.6 g/d (**Table 2**). The largely similar fetal growth over three parities coupled with reduced maternal growth can explain the greater difference between early and late gestation requirements in older versus younger sows.

Table 1. Characteristics of sows in experiments to determine amino acid requirements in early and late gestation at the University of Alberta

	Parity	n (sows)	n (observations)	Breeding weight, kg	ME intake, MJ/d
Threonine	2	6	71	165.5	32.0
Threonine	3 - 4	8	92	209.8	33.2
Isoleucine	4	7	76	231.7	34.5
Lysine	2 - 3	7	78	185.7	33.7
Tryptophan	2	6	68	167.7	33.2

Table 2. Total lysine[1], threonine[2], tryptophan[3] and isoleucine[3] requirements of gestating sows

		1st parity	**2nd parity**	**3rd, 4th parity**
Lysine	Early gestation	15.0	13.1	8.1
	Late gestation	18.0	18.4	13.0
Threonine	Early gestation	n/a[4]	7.0	5.0
	Late gestation	n/a	13.6	12.3
Tryptophan	Early gestation	n/a	1.7	n/a
	Late gestation	n/a	2.6	n/a
Isoleucine	Early gestation	n/a	n/a	3.6
	Late gestation	n/a	n/a	9.7

[1]Srichana (2006) for 1st parity, Samuel et al. (2010) for 2nd and 3rd parity [2] Levesque et al. (2011a); [3] not published [4]not available

Table 3. Change of sow performance from early (EG) to late gestation (LG) over 3 parities.

Parity		BW, kg	Maternal gain, kg	Protein retention, g/d	Energy retention, MJ/d	Litter size	Litter weight, kg
2	EG	177	44	32	3.0	13.8	19.5
2	LG	215		126	-0.7		
3	EG	205	40	38	1.2	13.6	20.1
3	LG	244		119	-0.9		
4	EG	240	25	4	1.5	15.8	22.1
4	LG	266		64	-1.3		

The increasing importance of maintenance, as a factor for requirements in early gestation with increasing age of sows, illustrates the need to reassess amino acid requirements for maintenance. The current estimates (NRC, 1998) for lysine and threonine maintenance requirement of 36 mg/kg$^{0.75}$ and 55 mg/kg$^{0.75}$ body weight, respectively, were determined in growing pigs (Fuller et al., 1989) and may not be appropriate for sows. In addition, the errors inherent in the nitrogen balance technique, i.e. overestimation of nitrogen retention, may result in determined maintenance requirements lower than the actual values. Recent results by Samuel et al. (2008) and Moehn et al. (2011) showed that the lysine and threonine maintenance requirements were appreciably greater at 49 mg/kg$^{0.75}$ and 98 mg/kg$^{0.75}$ body weight, respectively.

These changes in amino acid requirement have important consequences. First, the magnitude of change in requirements makes it nearly impossible to satisfy the requirements using a single diet during gestation. Second, the data show that the amino acid ratios change as pregnancy progresses and as sows age. Threonine and isoleucine requirements increased, relative to lysine, from early to late gestation while the tryptophan to lysine ratio showed little change. The threonine to lysine ratio was greater for both early and late gestation in the third vs. second parity. These changes in ideal amino acid ratios for sows are probably caused by the changing contributions of requirements for maintenance and maternal and fetal growth to total amino acid requirements. Because the ideal amino acid patterns differ among these factors of sow requirement (NRC, 1998), the ideal ratio for amino acids can be expected to change for the total daily requirement as well. That means that lysine may not be the first-limiting amino acid for older sows. This last point deserves further consideration in that the familiar order of limitation in growing finishing pigs may not apply to pregnant sows. In fact, Levesque et al. (2010) showed that threonine was likely the first limiting amino acid in multiparous sows in late gestation, tryptophan second limiting, and lysine and branched-chain amino acids third limiting, based on indicator amino acid oxidation and rates of protein turnover. Therefore, diet formulation for pregnant sows must account for markedly different ideal amino acid ratios compared to growing pigs and diet formulation for sows must take into account that different amino acids are first-limiting in corn-soybean meal diets (**Table 6**).

If a 2-phase feeding system is used in gestation, the question is when to change diets. McPherson et al. (2004) showed no change in fetal growth up to day 70 of gestation. Our results (Levesque et al. 2011b) indicate that the threonine requirement between day 63 and 73 of gestation was similar to that in early gestation, so that a change in gestation diets should occur after day 73. Heat production of sows changed little during early gestation but increased in late gestation, with an intersection of both phases at day 90 of pregnancy. If feed allowances are reduced by approximately 10% in early gestation (see below), heat production will decrease and intersect the late gestation phase earlier, i.e. on day 85 of pregnancy. Therefore, the suggestion of GfE (2008) appears appropriate, to use an early gestation diet from breeding to day 84 of pregnancy, and a late gestation diet from day 85 to farrowing.

The weight loss in the lactation preceding our requirement studies was moderate at 3.7 kg. If sows lose much more weight during lactation, the amino acid intakes in the following pregnancy may need adjustment to enable sows to regain lost body protein. 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 gestation for each 10 kg of body weight lost during the preceding lactation.

Energy Requirements during Gestation

It can be expected that energy requirements increase as pregnancy progresses because of sow weight gain and because of the exponential growth of fetuses. This is illustrated by our results that show positive energy balance in early gestation and negative energy balance in late gestation (**Table 3**), regardless of parity. Close et al. (1985) showed that 1st litter gilts lost 140 g/d of body lipid in late gestation when given a constant feed allowance. McMillan (2003) and Samuel et al. (2007) found that 2nd parity sows lost backfat in late gestation. Samuel et al. (2007) showed that 2nd parity sows increased heat production by 4.0 MJ/d from EG to LG and were in negative energy balance at day 105 of gestation. Ramonet et al. (2000) and McMillan (2003) showed that multiparous sows maintained positive energy balance throughout gestation. It therefore appears that 1st and 2nd parity sows clearly need additional feed allowance in late gestation while 3rd parity and older sows may need less adjustment to the feed allowance.

The GfE (2008) suggested to increase energy intake by 8 MJ/d metabolizable energy in late gestation for 1st to 3rd parity sows and by 6 MJ/d for 4th parity sows. To prevent the lipid loss of 140 g/d reported by Close et al. (1985), an additional energy intake of approximately 7.5 MJ/d metabolizable energy would be needed. The additional heat produced by 2nd parity sows in late gestation (Samuel et al., 2007) consisted of 1.5 MJ of energy to cover the increased maintenance requirement of heavier sows in late gestation and of 2.5 MJ of heat associated with maternal and fetal tissue gain. Applying the typical efficiency of energy retention of 0.70 (ARC, 1981), this means that a 2nd parity sow would need approximately 10 MJ/d ME more during late gestation to maintain the same energy status as in early gestation. However, the increase in energy intake in late gestation should be less than that to ease the transition to a catabolic state when lactation starts. Therefore, the feed allowance of corn-based diets should be increased in late gestation by 500-600 g/d for gilts and by 400-500 g/d for 2nd parity sows. Older sows, due to reduced or absent maternal gain, should be given 300-400 g/d additional feed in late gestation.

The benefits of increasing feed allowance especially for young sows are not only the maintenance of sows' body reserves before parturition, but also reduced backfat loss during lactation (Miller et al., 2000) so that less feed may be needed in the next parity to enable the sows to regain body mass lost in lactation. An additional benefit of reduced body mass loss in lactation is increased rebreeding success. Indeed, Shelton et al. (2009) found that additional 2 lbs (0.9 kg) fed to gilts in late gestation increased the conception rate after weaning from 77% to 95%. This effect was not seen in older sows.

Nutrient Availability for Sows

The data on ileal digestibility of dietary amino acids have been obtained almost exclusively from research with growing-finishing pigs. Although age or body weight has long been recognized as a factor influencing protein and energy digestibility (Ball and Aherne, 1987, CSIRO, 1987, Le Goff and Noblet, 2001), there are few studies of nutrient digestibility in sows. The greater true ileal digestibility of lysine and threonine in corn reported by Stein et al. (2001) has been confirmed by Levesque et al. (2011b) who showed that the availability of threonine in corn was greater by 6% in sows compared to growing pigs. However, Stein et al. (2001) found that the true ileal amino acid digestibility in wheat, barley and canola meal was similar for growing pigs and sows. Conversely, Levesque et al. (2011b) reported greater threonine availability in barley for sows than for growing pigs. This indicates a large degree of uncertainty regarding ileal amino acid digestibility in sows compared to growing pigs. Therefore, it is safer to apply values for growing pigs in diet formulation for sows until more data for ileal amino acid digestibility are available for sows.

The digestibility of energy and protein was shown to be greater in sows compared to growing pigs (Le Goff and Noblet, 2001) resulting in greater energy content for the same feedstuff when fed to sows. The digestible energy content of the same diets was on average 0.6 MJ/kg greater in sows than in growing pigs and this difference increased with increasing dietary fiber content (Le Goff and Noblet 2001). The increased urinary energy losses (affecting metabolizable energy) observed by Le Goff and Noblet (2001) in sows may have been caused by less than ideal amino acid nutrition. It can be expected that our proposed revised feeding regimen will improve sow amino acid nutrition so that increased energy losses can be avoided and the full benefit of increased dietary energy content can be applied to sows. Noblet et al. (2003) proposed that the net energy content in feedstuffs was 2 – 4% greater for sows than for growing-finishing pigs. Applying a 3% greater energy content for diet formulation or feed allocation for gestating sows appears justified.

Feeding Recommendations

Because of the changes in energy and amino acid requirements during gestation, a single phase feeding program will lead to overfeeding during early gestation and underfeeding during late gestation. Overfeeding in early gestation results in unwanted fat deposition, while underfeeding in late gestation leads to sows entering lactation in a severe catabolic state. Therefore, phase feeding gestating sows is necessary to supply nutrients in the right amount at the right time.

To control body condition, pregnant sows are fed restrictively. Therefore, energy intake is the limiting factor for gestating sows and, thus, the feed allowance to provide the necessary energy needs to be considered first when devising a sow feeding regimen. Generally, the feed allowance of sows is based on body weight and sow condition so that heavier and leaner animals are given more feed. For the purpose of this recommendation, ideal body condition is assumed in the first instance.

Using the University of Alberta sow feeding schedule as a starting point, typical first-litter gilts would receive 2.0 kg/d of a corn-based diet throughout gestation. The typical feed allowances for a 2nd parity sow would be 2.4 kg/d and for older sows 2.5 kg/d. These feed allowances are adequate to keep an average sow in good condition up to farrowing. However, when given a constant feed allowance in gestation, sows deposit body fat in early and mid gestation that is mobilized to supplement the inadequate energy intake in late gestation. This is energetically wasteful because both fat deposition and fat mobilization are less than 100% energy efficient. That means that the total feed eaten by a sow during gestation can be reduced slightly by introducing phase feeding compared to a single feed allowance while still providing for maintenance of the sow and allowing for the growth of the sow and conceptus. When introducing phase feeding, it is therefore necessary to reduce the feed intake in early and mid gestation to accommodate an increase in feed allowance in late gestation while slightly reducing the total feed eaten by a pregnant sow. If the feed allowance for a 1st and 2nd parity and older sow is increased by 0.6 kg/d, 0.5 kg/d and 0.4 kg/d, respectively, during the last 4 weeks of gestation, the daily feed offered needs to be reduced slightly during the first three quarters of pregnancy to achieve a small reduction in average gestation feed intake compared to constant feed allowance. These considerations lead to the feed amounts shown in **Table 4**. It must be noted that these feed amounts apply for sows of average body weight and condition; they should be modified for sows that are too lean or too fat, heavier or lighter than average, and more or less efficient in their nutrient utilization.

Table 4. Daily feed allowance (kg/d) of a corn-soybean meal based diet for average sows in good condition in early and late gestation.

	1st parity	**2nd parity**	**3rd parity and older**
Early gestation (day 1 to 84)	1.8	2.2	2.4
Late gestation (day 85 to 112)	2.4	2.7	2.8
Average daily feed:			
Phase feeding	1.95	2.32	2.50
Constant allowance	2.00	2.40	2.50

Given these feed allowances, the necessary amino acid contents (**Table 3**) needed to satisfy the daily requirements (**Table 2**) can be calculated.

Table 5. Necessary dietary total amino acid contents (g/kg) to satisfy the amino acid requirements given in Table 2 at the feed allowances given in Table 4.

		1st parity	**2nd parity**	**3rd parity and older**
Early gestation	Lysine	0.83	0.60	0.34
	Threonine		0.32	0.21
	Tryptophan		0.08	
	Isoleucine			0.15
Late gestation	Lysine	1.00	0.84	0.54
	Threonine		0.62	0.51
	Tryptophan		0.12	
	Isoleucine			0.40

As an example, we calculated corn-soybean meal diets (**Table 6**) that provide the total amino acids identified as requirements in **Table 5** given the feed allowances suggested in **Table 4**.

The necessary soybean meal (48% crude protein) contents range from 27.2% for late gestation gilts to 3.3% for early gestation older sows. A single diet cannot supply the needed amino acids satisfactorily and the range of amino acid requirements is so great that it cannot be overcome by simply increasing feed allowances of a single diet. Feeding a single diet for all pregnant sows would lead either to severe amino acid deficiency in younger sows, especially in late gestation, or substantial oversupply of amino acids in older sows, especially during early gestation. Either case would lead to considerable financial penalties from feeding a single diet instead of diets formulated specifically to meet amino acid requirements.

The second aspect that becomes clear in **Table 6** is that different amino acids drive the necessary inclusion rates of soybean meal. Because first parity gilts are essentially growing pigs that happen to be pregnant, lysine is the 1st limiting amino acid in corn soybean meal diets - similar to growing-finishing pigs. In older sows, however, requirements for fetal growth become more important in late gestation than the requirements for maternal growth and maintenance so that threonine becomes the 1st limiting amino acid instead of lysine. Older sows (3rd parity and up) in early gestation represent a different case altogether: because they have reached their adult body size, amino acid requirements are governed by the requirement for maintenance, and requirements for sow and fetal growth contribute only negligible amounts to the total amino acid requirement. Thus, diet formulation for pregnant sows needs to take into account the changing order of limitation of amino acids throughout a sows' life.

Table 6. Corn-soybean meal diets[1] to cover the amino acid requirements (Table 5) at suggested feed allowances (Table 4) for pregnant sows

	Parity:	1	2	3 and up
Early gestation	Corn	75.0	83.3	92.7
	Soybean meal	21.0	12.7	3.3
	Limiting AA[2]	Lysine	Lysine	Lysine, tryptophan (?)[3]
Late gestation	Corn	68.8	74.1	81.1
	Soybean meal	27.2	21.9	14.9
	Limiting AA	Lysine	Threonine	Threonine

[1]Default ingredient composition (NRC, 1998) for corn grain and soybean meal, solvent extracted, 44% crude protein. Diets contain 4% allowance for mineral and vitamin supplementation.
[2]Amino acid determining the necessary soybean meal content
[3]Tryptophan content was calculated as 0.077%

There are viable strategies to supply the necessary amino acids at given feed allowances. The preferred one is to formulate a diet that contains the maximum amino acid concentration needed ('high' diet) and one that contains the lowest amino acid concentration needed ('low' diet). For the intermediate amino acid concentration the 'high' and 'low' diets are then mixed in the appropriate ratios. The 'high' diet would need to contain a protein feedstuff, e.g. soybean meal or canola meal, while the 'low' diet may need no protein feedstuff at all, depending on the cereal used for diet formulation. The low diet, for example, could consist of barley only plus mineral and vitamin supplementation only. Feeding a 'high' and 'low' diet can be accomplished with computerized sow feeding stations or with two separate feed lines for sows in gestation stalls where both diets can be mixed according to individual sow's requirements. Such an approach would maximize the benefits of a parity-segregated phase feeding system.

A second possibility would be top dressing a single base ration. Because amino acid requirements differ more than energy requirements between parities and phases of gestation, a protein feedstuff, e.g. soybean meal, would be appropriate for top dressing. The amounts needed would be calculated as the difference between the required amino acids less those provided by the base diet and divided by the amino acid content of the top dressing feed. If soybean meal is used for top dressing corn-soy diets, the similar (metabolizable) energy contents of these feedstuffs would ensure energy intakes close to the requirement. However, because top dressing is manually dispensed, the additional labor and possible inaccuracies in dispensing make this option less than ideal.

If neither of these options is possible or wanted, sows can be grouped according to similar requirement. In this case, a decision needs to be made how to segregate diets. One option would be to use one diet for gilts in early and late gestation and for 2nd parity sows in late gestation and a second diet would be used for 2nd parity sows in early gestation and for older sows throughout pregnancy. A second option would be parity segregation, with one diet for gilts and 2nd parity sows and second diet for older sows. In either case, most of the benefits of parity segregated phase feeding will be lost.

From a nutrition and feed cost point of view, the option with ‘high’ and ‘low’ diets is the best; however its implementation may be hampered by costs to upgrade existing feeding equipment.

Conclusions

The recent results for amino acid and energy requirements of sows strongly support the need for parity-segregated phase feeding of pregnant sows. The phase feeding program should consist of two diets that satisfy the highest and lowest amino acid requirements and can be mixed in appropriate ratios to cover the intermediate amino acid needs. The feed amounts should be increased for the last four weeks of gestation. The increase in feed allowance of a corn-soybean meal diet should be 0.6 kg/d for gilts, 0.5 kg/d for 2nd parity sows and approximately 0.4 kg/d for older sows. Such a feeding program requires slightly less feed during gestation compared to single phase feeding but supplies amino acids and energy to the sows in the right amounts at the right time.

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