Recent breakthrough findings in essential fatty acid nutrition and seasonal infertility

David Rosero[1,2], PhD; R. Dean Boyd[1,2], PhD; Eric van Heugten[2], PhD
[1]The Hanor Company, Franklin, Kentucky; [2]North Carolina State University, Raleigh, North Carolina

Introduction

The nutritional requirements of the prolific (14.6 pigs per litter) and high-producing (26.6 pigs weaned per year) modern lactating sows (upper 10 percentile[1]) have increased substantially because of genetic improvements for litter size. For larger and rapid-growing litters (10.2 weaned pigs growing at 2.46 kg/d), the demand for milk production has increased dramatically, as the modern sow needs to produce nearly 10 kg of milk/d, which is much greater than the standard sow of the past, producing about 7.5 kg/d.[2] Nevertheless, the development of the modern lactating sow has also resulted in an animal with less body fat reserves and lower appetite.

Ensuring the optimal nutrition of the high producing sow becomes particularly important to maximize lactation output and long-term productivity. Limitation of energy and nutrient intake is challenging for the sow, resulting in the mobilization of body reserves to replace the nutrient deficiency. Supplemental lipids are of particular importance in sow nutrition programs due to the higher energy density and lower heat increment associated with digestion and metabolism when compared to carbohydrates, fibers and proteins. Although, supplemental lipids are extensively used in sow lactation diets as concentrated sources of energy, their nutritional value is not limited to energy as lipids are also important sources of essential fatty acids (EFA, linoleic acid, C18:2n-6; and α-linolenic acid, C18:3n-3). The present manuscript discusses recent studies that investigated the effects of supplemental EFA in diets of the modern and high producing lactating sow.

Nutritional value of lipids during lactation

Potential benefits of supplemental lipids on the lactating sow and her progeny have been extensively studied over the last 30 years, but results from studies are inconsistent. Pettigrew[3] and Pettigrew and Moser[4] reviewed published studies that investigated the effects of supplemental dietary lipids on lactating sow performance. It was concluded that lipid supplementation increased caloric intake in spite of feed intake reductions stemming from external factors such as high temperatures. Increased caloric intake resulted in inconsistent improvements in milk fat secretion and weaning weight of piglets. Positive responses occurred when diets were supplemented with at least 8% of lipids, in herds where pre-weaning mortality was higher than 20% or when sows were experiencing heat stress.

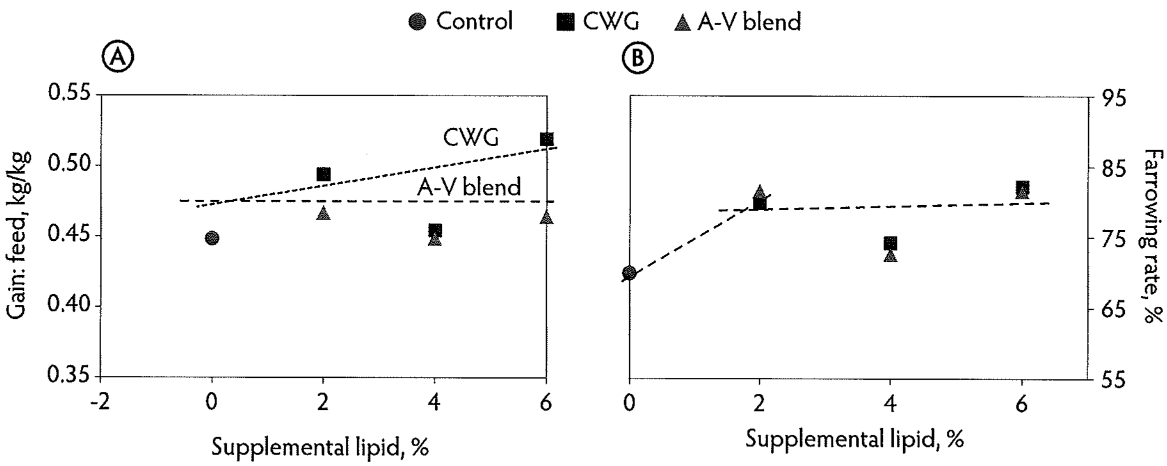
It is plausible that supplemental lipids have a greater impact when fed to the prolific and high-producing modern lactating sows because of the greater pressure for milk production. To test this hypothesis and to determine the optimal dietary level of lipid, we conducted two dose-response research studies using over 300 sows (in each trial) in a commercial farm in Oklahoma during summer months.[5,6] Sows were fed either a control diet (without supplemental lipid) or diets supplemented with animal-vegetable blend (A-V blend) or choice white grease (CWG), as lipid sources, in increments of 2% (up to 6%). Confirming previous observations, caloric intake of lactating sows increased with the addition of either lipid source. Extra caloric intake moderately improved (CWG) or did not improve (A-V blend) lactating sow performance (Figure 1A).

The most intriguing finding of our research was that lactating sows fed diets without supplemental lipids had poor subsequent reproduction (farrowing rate < 72%), but this was remarkably improved by theinclusion of only 2% supplemental lipid to lactation diets (Figure 1B). In these studies, milk samples were collected from a subset of 30 sows fed either a control diet or diets supplemented with 6% A-V blend or CWG.[7] Results revealed that lactating sows fed the control diet secreted in milk (66 g/d) a greater amount of linoleic acid than the amount consumed (64 g/d). It seemed that this typical corn-soybean meal diet without added lipid did not provided sufficient linoleic acid to sows. Apparently, supplementation of at least 2% lipids provided to sows the required levels of linoleic acid. We hypothesized that the benefits observed on subsequent reproduction in these studies were due to the supplementation of EFA from addition of lipids to diets.

Lipids as sources of essential fatty acids

The studies conducted by Rosero et al.[5,6] caused one to consider the fact that lipids bring specific fatty acids that are known to be essential to performance. The essentiality of linoleic acid and a-linolenic acid in animals is due

Figure 1: Effects of increasing supplemental lipids on (A) lactating sow performance (Gain:Feed ratio) and (B) subsequent farrowing rate (percentage of sows that farrowed in the subsequent cycle) of sows. Sows were supplemented with either animal-vegetable blend (A-V blend) or choice white grease (CWG) as lipid sources.[5,6]



to the absence of desaturase enzymes that are able to introduce double bounds distal from carbon 10 of octadecenoic acids. These fatty acids play important biological roles in the development of young animals and are precursors of hormones important for reproduction of females.[8,9] The former has been extensively studied in gestating sows and neonatal pigs; but the importance of the later has not been investigated in lactating sows. In dairy cows, provision of supplemental linoleic acid during lactation improved the subsequent reproduction.[10] Linoleic acid is a precursor of prostaglandin F2a, which is an important hormone that is involved in diverse stages of reproduction, such as ovulation, luteal regression, implantation, uterine involution and post-partum physiology.[9]

Supplemental linoleic acid was not proven to be limited for sows that weaned a relatively low number of slowly-growing pigs (weaned pigs = 7.1 and litter growth rate = 1.36 kg/d).[11] It was concluded that a practical diet without added lipids provided sufficient linoleic acid to sows with relatively low pig output. We suggest that this may not hold true for the modern sow because of the significantly greater pressure for milk production and milk fatty acid output. Under these conditions, a diet without supplemental linoleic acid may result in deficiencies that could affect the subsequent reproduction of sows. We estimate that a negative balance of linoleic acid exits for sows consuming a diet without added lipids and propose that this could explain the poor or intermittently poor subsequent reproductive performance of sows.

Balance of essential fatty acids during lactation

Given the essentiality of linoleic and α-linolenic acids for the development of the neonatal pig, our rationale is that the lactating female attempts to maximize the secretion of these fatty acids in milk, even if this results in mobilization from body reserves. To investigate further this hypothesis, we conducted the next study and computed the estimated balance of EFA during lactation.[12] A total of 50 lactating sows were assigned randomly to a 2 x 2 factorial arrangement of diets plus a control diet without added lipid. Factors included linoleic (2.1 and 3.3%) and α-linolenic acid (0.15 and 0.45%), obtained by adding 4% of mixtures of canola, corn, and flaxseed oils to diets. The estimated balance of EFA was computed as the apparently available intake of EFA from the diet minus the outflow of EFA in milk. Supplemental EFA increased milk concentrations of both linoleic and α-linolenic acid in a dose-response manner. For sows consuming control diet, the balance of EFA was relatively low (18.1 and 1.3 g/d, for linoleic and α-linolenic acid, respectively) and similar to the balance for sows consuming diets with low levels of EFA (15.1 and 1.0 g/d, for 2.1% linoleic and 0.15% α-linolenic acid, respectively). Supplemental EFA greatly increased the balance of EFA (33.6 and 8.6 g/d for 3.3% linoleic and 0.45% α-linolenic acid, respectively).

In addition, we analyzed data of 3 published studies that provided sufficient data regarding fatty acid composition (both diet and milk), feed intake and litter growth performance.[13-15] Data of these studies and the studies conducted in our laboratory[16] were used to estimate the EFA balance. For sows fed corn soybean meal diets without added lipids, linoleic acid intake was estimated to be 68 g/d and the amount of linoleic acid secreted in milk averaged 60 g/d. These sows had a relatively low estimated balance of linoleic acid. Increasing supplementation of linoleic acid increased output in milk and balance (Figure 2a). The balance of α-linolenic acid seemed to be positive, but relatively low. Similarly to the balance of linoleic acid, lipid supplementation (especially sources such as flaxseed and rapeseed oils) increased the intake, output in milk and balance of this fatty acid (Figure 2b).

We acknowledge that our estimated balance of EFA is an over-estimate of diet adequacy because the equation does not account for other routes for EFA use and the possibility for mobilization from adipose tissue. If other routes for EFA use are considered in our equation, it is possible that sows fed diets not supplemented with lipids had a negative EFA balance during lactation. Other detailed studies are needed for a better estimation of the net balance of EFA. Nevertheless, our estimated balance highlighted the potential nutritional deficiency of EFA during lactation.

Essential fatty acids and subsequent reproduction of sows

Research in this area has been limited because it is commonly thought that diets, based on commonly used cereal grains and protein supplements, provide the amounts of linoleic acid required by lactating sows. A next study was conducted to define the minimum levels of EFA required by the prolific and high producing sow for optimal subsequent reproduction.[17] A total of 480 lactating sows (equally balanced by parity 1, and 3 to 5, P3+) were assigned randomly to a 3 × 3 factorial arrangement plus a control diet without added lipid. Factors included linoleic (2.1, 2.7 and 3.3%) and α-linolenic acid (0.15, 0.30 and 0.45%), obtained by adding 4% of mixtures of canola, corn, and flaxseed oils to diets.

Supplementation of EFA did not affect lactating sow performance but it improved the subsequent reproductive performance of sows depending on parity. For parity 1 sows, α-linolenic acid linearly reduced the farrowing rate (88.7, 90.3 and 80.2% for 0.15, 0.30 and 0.45% α-linolenic acid, respectively). The effects of linoleic acid on the subsequent reproduction of P3+ sows were influenced by the level of α-linolenic acid in the diet. For diets containing less than 2.7% linoleic acid, α-linolenic acid at 0.45% resulted in the highest farrowing rate (> 95%). For diets containing less than 0.45% α-linolenic acid, supplemental linoleic acid improved farrowing rate of P3+ sows (Figure 3a). These improvements in farrowing rate were related with a reduced number of sows showing irregular returns (> 24 d after breeding) and not to an impact on conception rate (Figure 3b). Apparently, sows fed adequate amounts of linoleic acid were able to maintain pregnancy. In addition, supplemental linoleic acid linearly increased the subsequent litter size of parity 1 and P3+ sows (13.2, 14.1, and 14.0 pigs for 2.1, 2.7, and 3.3% linoleic acid, respectively).

The results demonstrated that supplementation of linoleic acid increased the subsequent litter size and, depending on parity, improved the subsequent reproductive cycle of sows. The contrary response of parity 1 sows (detrimental farrowing rate) and P3+ sows (improved farrowing rate) to supplementation of high levels of α-linolenic acid (0.45%) highlight the need for a better understanding of

Figure 2: Effect of increasing (A) linoleic or (B) α-linolenic acid supplementation to lactation diets on the estimated EFA balance (dietary intake minus output in milk). It was assumed that 100% of linoleic acid consumed was digested and that 100% of the net uptake of EFA was secreted in milk. Symbols represent least square means (n = 5 to 10 sows per symbol) from published studies.[13-15]

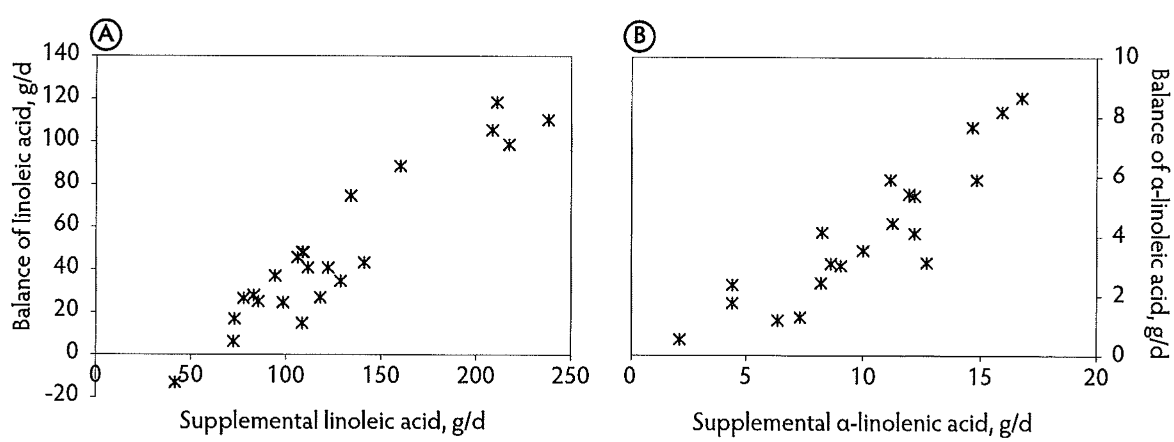
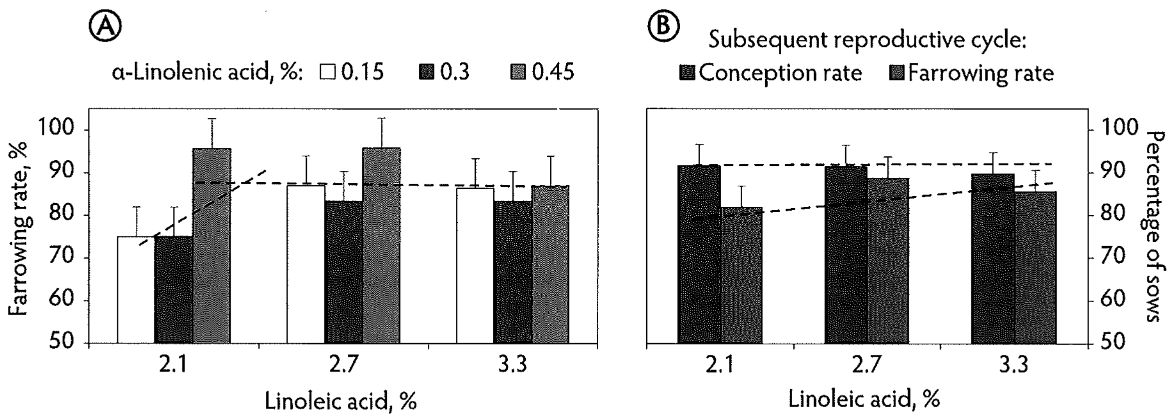


Figure 3: Effects of supplemental EFA during lactating on the subsequent conception (percentage of sows that were pregnant at d 35 of gestation) and farrowing (percentage of sows that farrowed in the subsequent cycle) rates of P3+ sows. (A) Subsequent farrowing rate of sows fed supplemental linoleic and α-linolenic acid during lactation. Bars represent least square means ± SEM (n = 22 to 24 sows). (B) Subsequent conception and farrowing rates of sows fed diets supplemented with linoleic acid during lactation. Bars represent least square means ± SEM (n = 71, 71 and 69 sows for 2.1, 2.7 and 3.3% linoleic acid, respectively).



the metabolic response of sows to this fatty acid and to the n-6:n:3 fatty acid ratio.

We further analyzed data from previous studies[5,6] and the study described above. We observed that farrowing rates were improved with the consumption of at least 100 g/d of linoleic acid, and no further improvements thereafter (Figure 4).

Proposed recommendations for essential fatty acids

Despite the essentiality of EFA during lactation, current NRC[18] dietary recommendations for sows specify a low requirement for linoleic acid (6 g/d) and no requirement minimum or maximum estimate for α-linolenic acid is specified. It is important to note that the requirement of linoleic acid is based on studies using growing pigs, because studies using lactating sows were limited. We suggest that the application of this requirement to sow lactation diets is inaccurate because of the obvious differences in physiological state between growing pigs (positive energy balance) and lactating sows (negative energy balance). Compared with the least amount of linoleic acid secreted in milk (60 g/d), the current recommendation estimate of 6 g/d is logically too low. Based on the response on the subsequent farrowing rate, we suggest a minimum requirement of 100 g/d of linoleic acid for lactating sows.

Table 1 illustrates the practical application of the proposed minimum requirement of linoleic acid using commercially available lipid sources. Traditionally, lipids are evaluated based the cost per unit of energy. However, our results demonstrated that the primary value of lipids during lactation should be based on the cost per unit of linoleic acid provided. Although supplemental α-linolenic acid did not result in consistent response in the subsequent reproduction of sows, we recognize the biological importance of this fatty acid. Further studies should be directed to obtain a minimum requirement of this fatty acid. This could be applied in practical diets along with the n-6:n-3 fatty acid ratio greater than 10, suggested by Eastwood et at.[14]

Conclusions

Understanding the requirements of the prolific and high-producing lactating sow is important to design nutritional programs oriented to maximize the biological potential of growth of the nursing litters and to maximize the long-term productivity of the sow. The experiments, described throughout this manuscript, demonstrated that the nutritional value of lipids is not limited to energy, because lipids are also important sources of essential fatty acids. It was demonstrated that linoleic acid supplementation during lactation directly affects subsequent reproduction and that this phenomenon is increasingly important with advancing sow age. We recommend the provision of 100 g/d of linoleic acid to lactating sows, and suggest that this will ensure adequate consumption of this fatty acid and prevent a potential negative balance.

Figure 4: Effects of increasing linoleic acid intake on the subsequent farrowing rate of mature (parities 3-5) sows. Compilation of the farrowing rates (n = 27 to 72 sows per symbol for a total of 553 sows) from sow studies.[5,6]

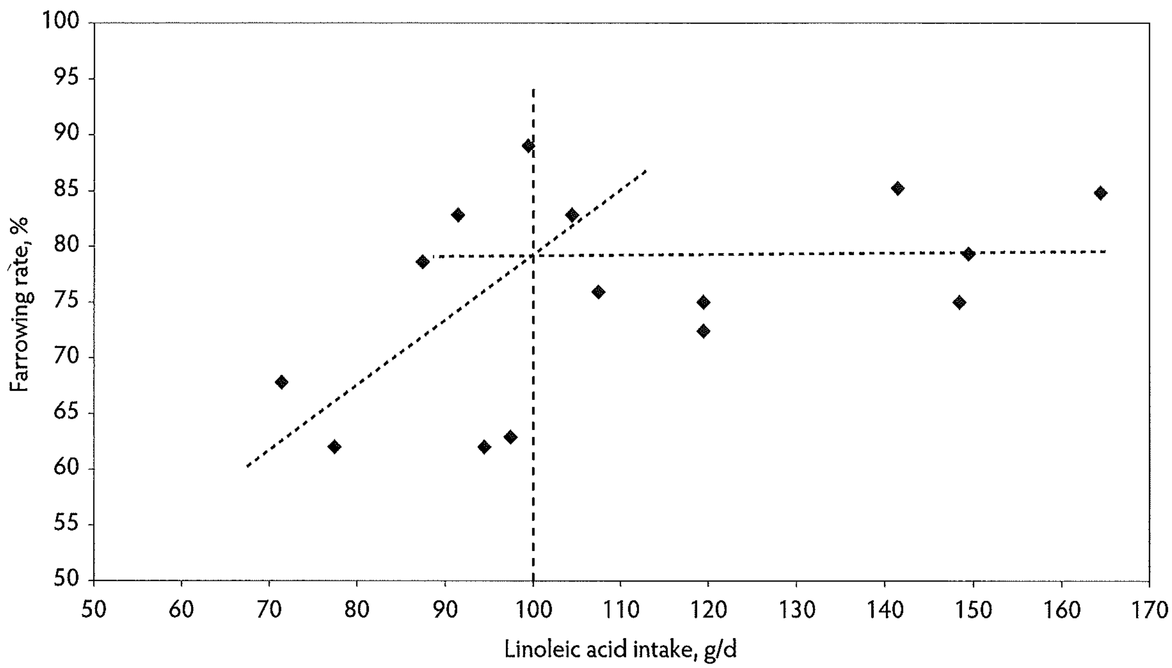


Table 1: Comparison of the nutritional value of commonly used lipid sources when supplemented to lactation sow diets.

		Lipid as linoleic acid source		Lipid as energy source		Lactation diet (100 g/d linoleic acid)[1]	
Lipid source[2]	**Price,[3] $/kg**	**Linoleic acid,[4] %**	**Cost, $/kg of linoleic acid**	**NRC ME,[4] Mcal/kg**	**Cost, $/Mcal ME**	**Added lipid**	**Cost of added lipid, $**
A-V blend	0.87	26.9	3.2	8.225	0.106	1.5	1.3
CWG	0.91	12.6	7.2	8.124	0.112	3.2	2.9
Poultry fat	0.88	21.4	4.1	8.364	0.105	1.9	1.6
Tallow	0.91	3.0	30.3	7.835	0.116	13.3	12.1
Corn oil[5]	1.05	53.5	2.0	8.579	0.122	0.7	0.7
Soybean oil	1.28	54.6	2.3	8.574	0.149	0.7	0.9

1 Common corn-soybean meal lactation diet formulated to provide the recommended 100 g/d of linoleic acid to sows. Assuming a daily feed intake of 5 kg.

2 CWG: choice white grease; A-V blend: animal-vegetable blend.

3 Prices of lipid sources published in Feedstuffs magazine as of May 2014.

4 Fatty acid composition and metabolizable energy of lipid sources published in the current NRC (2012; Table 17-4).

5 Nutritional value of corn oil after verification of peroxidation status. There are suggestions that corn oil derived from DDGS have a questionable quality and (or) peroxidation status. This aspect must be validated prior to Corn oil from a particular source is used. Fats typically are not stabilized, except by request or upon delivery to the Feed Mill.

References

1. PigChamp. 2011. PigChamp bench marking, country comparisons. Accessed May. 29, 2014. www.pigchamp.com/Products/Benchmarking.aspx.

2. Boyd, R. D., K. J. Touchette, G. C. Castro, M. E. Johnston, K. U. Lee, and I. K. Han. 2000. Recent advances in amino acid and energy nutrition of prolific sows - Invited Review. *Asian-Australian J Anim Sci* 13:1638–1652.

3. Pettigrew, J. E. 1981. Supplemental fat for peripartal sows: A review. *J Anim Sci* 53:107–117.

4. Pettigrew, J. E., and R. L. Moser. 1991. Fat in Swine Nutrition. Pages 133–145 in Swine Nutrition. E. R. Miller, D. E. Ullrey, and A. J. Lewis, ed. Butterworth-Heinemann, Boston, MA.

5. Rosero, D. S., E. van Heugten, J. Odle, R. Cabrera, C. Arellano, and R. D. Boyd. 2012a. Sow and litter response to supplemental dietary fat in lactation diets during high ambient temperatures. *J Anim Sci* 90:550–559.

6. Rosero, D. S., E. van Heugten, J. Odle, C. Arellano, and R. D. Boyd. 2012b. Response of the modern lactating sow and progeny to source and level of supplemental dietary fat during high ambient temperatures. *J Anim Sci* 90:2609–2619.

7. Rosero, D. S., E. van Heugten, J. Odle, V. Fellner, and R. D. Boyd. 2011. Impact of dietary fat on milk composition, milk output and apparent digestibility is fat source dependent in lactating sows. *J Anim Sci* 89(Suppl. 1):755. (Abstr.)

8. Innis, S. M. 2007. Dietary (n-3) fatty acids and brain development. *J Nutr.* 137:855–859.

9. Weems, C. W., Y. S. Weems, and R. D. Randel. 2006. Prostaglandins and reproduction of farm animals. *Vet J* 171:206–228

10. Thatcher, W. W., T. R. Bilby, J. A. Bartolome, F. Silvestre, C. R. Staples, and J. E. P. Santos. 2006. Strategies for improving fertility in the modern dairy cow. *Theriogenology* 65:30–44.

11. Kruse, P. E., V. Danielsen, H. E. Nielsen, and K. Christensen. 1977. The influence of different dietary levels of linoleic acid on reproductive performance and fatty acid composition of milk fat and plasma lipids in pigs. *Acta Agric Scand* 27:289–296.

12. Rosero D. S., S. Mendoza, J. Odle, R. D. Boyd, V. Fellner, and E. van Heugten. 2014. Impact of dietary lipids on milk composition and balance of essential fatty acids during lactation. *J Anim Sci* (in review)

13. Seerley, R. W., T. A. Pace, C. W. Foley, and R. D. Scarth. 1974. Effect of energy intake prior to parturition on milk lipids and survival rate, thermostability and carcass composition of piglets. *J Anim Sci* 38:64–70.

14. Eastwood, L. 2012. The role of omega-6 to omega-3 fatty acid ratios in sow diets on reproduction, piglet performance, fatty acid profiles, lactational fat mobilization and piglet health post-weaning. PhD Diss. University of Saskatchewan, Saskatoon.

15. Lauridsen, C., and V. Danielsen. 2004. Lactational dietary fat levels and sources influence milk composition and performance of sows and their progeny. *Livest Prod Sci* 91:95–105.

16. Rosero, D. 2014. Nutritional Value of Dietary Lipids in Lactating Sow Diets. PhD Diss. North Carolina State University, Raleigh NC.

17. Rosero D. S.,E. van Heugten, J. Odle, M. McCulley, and R. D. Boyd. 2014. Response of sow and progeny to supplementation of dietary essential fatty acids during lactation. *J Anim Sci* 92(Suppl. 2):144. (Abstr.)

18. NRC. 2012. Nutrient Requirements of Swine. 11th ed. Nat. Acad. Press, Washington, DC.