

Nutrient Requirements of Prolific Sows

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■ Summary

The nutrient requirements of modern sows, and the availability of dietary nutrients for sows, are very poorly known in comparison to our knowledge of growing pigs. The number of published research papers in the last 40 years on growing pig nutrition is in the tens of thousands, however, there are only about 800 publications on sow nutrition listed in the Commonwealth Agricultural Bureau database – less than 1% of all publications concerning pigs. If we still don't know everything we need to about how to feed growing pigs – imagine what we don't know about sows!

The productivity of sows has increased dramatically in the last 20 years, however, the research, upon which current dietary recommendations are based, dates from the late 1970's to the early 1990's (ARC 1981, NRC 1998). In addition, many of the nutrient recommendations for sows are unverified extrapolations from research in growing pigs. Our recent research shows that the current recommendations for both energy and amino acid intake in sows (NRC 1998) are incorrect by a significant margin. The economic benefit to producers of research to revise and update the energy and amino acid requirements of sows is estimated to be worth in excess of **\$4.50** per pig marketed (Grier et al 2006).

■ Introduction

Sows are of central importance to pork production because they are the reproductive unit of the swine herd and their productivity and genetic potential defines the maximum potential productivity of the entire system. Although sows represent a numerically small fraction of the total pig herd, sows consume 20% of the feed in farrow-to-finish pork production and thus have a very large impact on the overall feed cost per kg of pork produced. Improper

diets have many negative effects on sow performance, including: reduced longevity, less resistance to disease, poor rebreeding success, fewer pigs per litter born and weaned, lower piglet birth and weaning weights, and greater variation in piglet weight and growth potential. An incorrect balance between energy and amino acid intake in sows will also result in sub-optimal body composition, including, either too little or too much backfat, reduced feed intake during lactation, and too great a loss of body protein during lactation. Highly prolific sows demonstrate many problems that we also attribute to poor nutrition, including, increased piglet mortality, increased litter variation and increased weight loss in lactation (Boulot et al., 2008; Foxcroft, 2008).

During gestation, approximately 20 to 40% of the energy and amino acids consumed by sows are used for growth of the conceptus (piglets and products of gestation) (NRC 1998), which accounts for an increasing proportion of the energy and amino acid requirement as the sow approaches parturition. The remaining 60 to 80 percent of the energy and amino acids consumed by the sows are used for maintenance of normal metabolism and activities of the body. Therefore, research on energy and amino acid requirements of sows must begin with accurate estimates of maintenance requirements for energy and amino acids. Maintenance requirements are the basal values to which we add the energy and amino acid requirements for growth of the sow, growth of the fetal pigs and conceptus, and lactation. If this basal value for maintenance is wrong, then all the subsequent values will also be wrong.

Although lactation typically only lasts about 21 days, compared to 114-116 days for gestation, the impact of lactation on the metabolism of the sow is much greater than any other healthy physiological state. In fact, lactation has such massive catabolic effects on the body that lactation is often used as a model to study metabolism during severe weight loss following major trauma and in terminally ill cancer patients (Baracos, 2006). Nutrient requirements of sows during lactation are extremely difficult to study because the requirements change daily due to changes in: milk production and composition, voluntary feed intake, body weight loss and the composition of that weight loss. Therefore, very rapid and sensitive methods are required to study energy and amino acid requirements during lactation. Our indicator amino acid oxidation system is the ideal method for the study of lactation requirements for amino acids. Likewise, calorimetry is the best method to study energy metabolism during lactation because it is also rapid and sensitive.

■ Increases in Sow Productivity during the last 10 Years

The productivity and characteristics of sows during 1998 are compared to current sows in **Table 1** and **Figure 1**. Even in this short period of only 10 years, sow productivity has increased significantly.

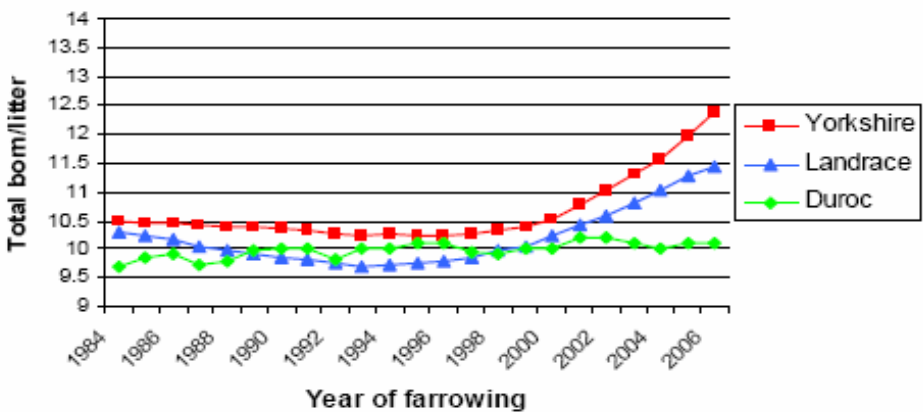
Table 1. Comparison of Sow Productivity in Canada – 1998 & 2004

Characteristic	1998 ^a	2004 ^b
Repeat services, %	10.7	9.2
Farrowing rate	75.6	84.3
Average non-productive days	61.2	56.2 ^c
Piglets born per litter	11.4	12.1
Litters per year	2.31	2.33
Piglets born per year	26.33	28.19
Piglets weaned per year	21.48	22.53
Age of litter at weaning (d)	21.3	20.43
Weight of litter at weaning (kg)	60	62.46
Days from weaning to re-breeding	6.7	7.5 ^c

^a PigChamp Datashare 1998 - Annual data for Canada, n = 213

^b PigChamp Datashare 2004 - Annual data for Canada, n = 39

^c PigChamp Datashare 2003 - Annual data for Canada, n = 61
(http://www.pigchamp.com/summary_archives.html)

Figure 1. Genetic trends for litter size – 1984 to 2007^a

^a Adapted from “Canadian Centre for Swine Improvement, Annual Report 2006/2007” (<http://www.ccsi.ca/meetings/annual/ann2007.pdf>)

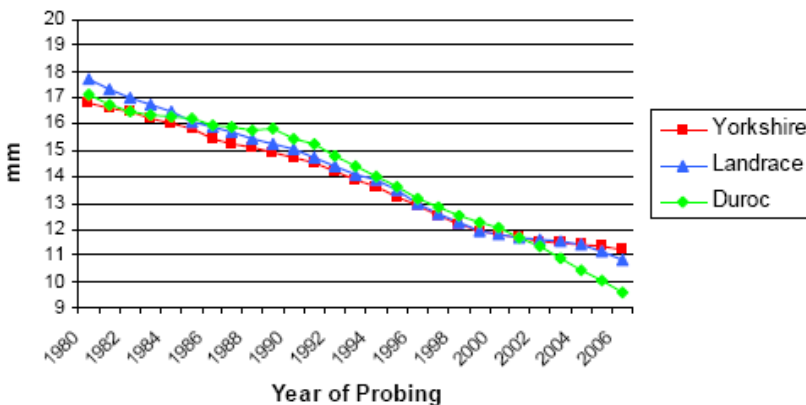
Modern sows have more piglets born per litter, rear more and heavier piglets to weaning, have more lactations per year, and re-breed faster and more consistently. Nutrient recommendations based upon research with sows that were much less prolific and productive than those currently on farms should be suspect. The current NRC (1998) produced a mathematical model that attempted to take many of these productivity factors into account and thus

predict the effects on nutrient requirements. However, as discussed below, intense genetic selection has changed the basal metabolism of pigs. Thus the fundamental data underlying the current models for sow feeding must be updated.

■ Energy and Protein Metabolism in Sows Changes with Increasing Productivity in Growing Pigs

In a review of heat production by swine (Brown-Brandl et al 2004), the authors concluded that for daily heat production (HP) “data for greater than 90 kg pigs” was insufficient. Equally important, Brown-Brandl et al (2004) calculated that the HP of growing pigs had increased 18.1% (approximately 1% per year) during the period 1984 to 2002, due to changes in average body composition of the animals (more muscle, less fat) (**Figure 2**) and increases in the rate of lean tissue growth (**Figure 3**). Tess et al. (1984) calculated that for every 2.1% increase in lean tissue percentage there should be increase in HP of 18.7%.

Figure 2. Genetic trends for backfat at 100kg – 1984 to 2007^a

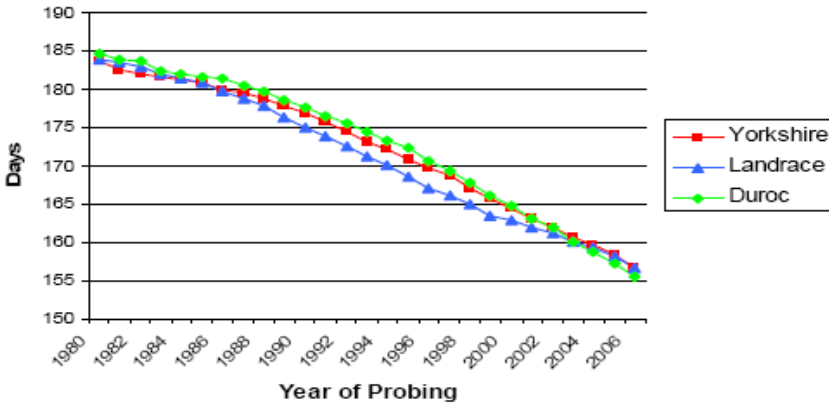


^a Adapted from “Canadian Centre for Swine Improvement, Annual Report 2006/2007” (<http://www.ccsi.ca/meetings/annual/ann2007.pdf>)

The rate of lean tissue turnover (i.e. the rate of protein synthesis and breakdown), which contributes to both energy and amino acid requirement, also increases as lean growth rate increases in pigs. Wenk et al (1980) argued that the metabolizable energy for maintenance (ME_m) must be increased as the rate of lean tissue turnover is increased. Although there have been several estimates of protein turnover in growing pigs, we were unable to find any published estimates of protein turnover rate in sows. Protein turnover rate is a critical value because it affects both energy and protein requirement of the pig (Kolstad and Vangen, 1996). We have planned

a series of a repeated measures experiments in which we will simultaneously measure protein turnover (to estimate protein requirement), heat production (to estimate energy requirement) and respiratory quotient (estimate of nutrient utilization) in individual sows as they progress through gestation and lactation. See Samuel et al (2008b) in these proceedings for a preliminary report on one experiment in this program.

Figure 3. Genetic trends for age at 100kg – 1984 to 2007 ^a



^a Adapted from “Canadian Centre for Swine Improvement, Annual Report 2006/2007” (<http://www.ccsi.ca/meetings/annual/ann2007.pdf>)

Increased HP by swine has significant implications for building design and management. Brown-Brandl et al. 2004 stated that the increased HP by pigs must be accounted for in current agricultural building designs. The American Society of Agricultural Engineers Standards (2003) refers to experiments performed by Bond et al. (1959) for the heat production parameters required to calculate adequate ventilation for modern pig production. Therefore, more current and accurate estimates of maintenance energy are not only required by nutritionists but also by agricultural engineers to ensure adequate ventilation and building design.

■ Maintenance Energy Requirement – Current Values for Swine

Estimates of the energy requirements for swine were summarized by the NRC (1998); the mean daily maintenance energy requirement (ME_m) was estimated to be 106 kcal ME/kg $BW^{0.75}$ (444 kJ/kg $BW^{0.75}$). This was based on only ten literature values, which covered an almost 2-fold range, from 92 to 160 kcal ME/kg $BW^{0.75}$. Of these ten experimental values used to define the daily energy requirement for all swine, four experiments used early-weaned (less than 21 d suckling) piglets (Böhme et al, 1980; Noblet and Le Dividich, 1982;

Campbell and Dunkin, 1983; Close and Stanier, 1984), two experiments used normally weaned (more than 21 days suckling) piglets (McNutt and Ewan, 1984; Gädeken et al, 1985), and three values were for growing pigs 20 to 120 kg BW (Whittemore, 1976; Wenk et al, 1980; Noblet et al, 1985). The additional reference was to an earlier review of ME_m by ARC (1981). ARC (1981) used a number of sources covering a large body weight range of 2 to 180 kg live weight and estimated the daily ME_m for swine to be 458 kJ/kg $BW^{0.75}$. Therefore, the current estimates of ME_m for sows, based on the 27 year old review of ARC (1981) and the 10 year old review by NRC (1998) are 109 and 106 kcal/kg $BW^{0.75}$, equivalent to 458 and 444 kJ/kg $BW^{0.75}$, respectively.

There are relatively few reports specifically reporting the ME_m for sows. These have been summarized in **Table 2**. These experiments varied widely in physiological state, parity, weights of the sows, energy intake, method of measuring energy status, individual vs. group housing, and control of the ambient temperature. These many differences in methodology and design make it very difficult to arrive at an average recommendation for the ME_m for sows. Experiments conducted with gilts (primiparous) must be discounted because these animals would be growing at a significant rate and the information is generally lacking in these papers to account for effect of the changes in weight and body composition. Many of these estimates were also collected when the sows were not in thermoneutral environments (e.g. during winter or at 5 C temperature) and thus the energy requirement was usually overestimated by an unknown amount because variations in ventilation, bedding, humidity etc, which all affect the HP of the sows, were often not fully reported or accounted for. The comparative slaughter method suffers from systemic errors that are known to result in over estimates of energy requirement; few of the published reports using comparative slaughter provided the information to account for or remove these possible sources of error. ME_m is most accurately measured when the pigs are fed an energy intake that is close to their actual ME_m (Gray and McCracken 1980). When animals are fed at greater than their actual ME_m energy requirement body composition changes, with an increasing deposition of fat relative to protein as the energy intake, exceeds the requirement by greater amounts. This results in an under-estimate of maintenance energy requirement because it takes less energy to maintain a kg of fat than a kg of protein. Rate of metabolism of the sow adjusts to the greater energy intake and the efficiency of energy use changes (decreases), also resulting in an overestimate of ME_m . If sows are fed below the actual ME_m , they lose weight and body composition changes; these composition changes must be accurately measured to account for the energy released by the breakdown of body fat and protein. Finally, when sows receive more feed they tend to reduce their activity (less standing, walking etc) thus reducing energy expenditure. Therefore, experiments to measure ME_m of sows should be designed to use a plane of nutrition as near to the actual ME_m energy intake as possible.

Table 2. Estimates of maintenance energy requirement for sows

ME_m^a	Weight, kg	Parity^b	Status^c	Comments	Reference
506	150 – 220	M	NP	Fed 1x and 2x estimated of ME _m ; calorimetry	Samuel et al, 2007c
418	133 – 219	Pr	P	average from early (30-50 d), middle (50-80 d), & late (95-110 d) gestation; calorimetry	Noblet and Etienne, 1987
422	105 – 203	Pr	P	Calorimetry	Close et al, 1985
420	105 – 203	Pr	NP	Calorimetry	Close et al, 1985
427	100 – 162	Pr	P	Calorimetry	Burlacu et al, 1983
513	115 - ?	Pr	P	Used the energy coefficients of Thorbek (1975); comparative slaughter	De Wilde, 1980
502	115 - ?	Pr	NP	Used the energy coefficients of Thorbek (1975); comparative slaughter	De Wilde, 1980
407	116 – 200	Pr	P	average from early (40-60 d), middle (60-80 d), & late (90-110 d) gestation; calorimetry	Noblet and Close, 1980
409	114 – 154	Pr	NP	average from early (40-60 d), middle (60-80 d), & late (90-110 d) gestation; calorimetry	Noblet and Close, 1980

452	130 – 180	Pr	P	average from d 56 and d 112 gestation; comparative slaughter; summer	Lodge et al., 1979
452	130 – 161	Pr	NP	average from d 56 and d 112 gestation; comparative slaughter; summer	Lodge et al., 1979
661	118 – 146	Pr	P	average from d 56 and d 112 gestation; comparative slaughter; winter	Lodge et al., 1979
640	120 – 132	Pr	NP	average from d 56 and d 112 gestation; comparative slaughter; winter	Lodge et al., 1979
753		Pr	NP	housed at 5 °C; comparative slaughter	Hovell et al, 1977
476		Pr	NP	housed at 5 °C; comparative slaughter	Hovell et al, 1977
530*		Pr	P	comparative slaughter	Hovell et al, 1977
444	128 – 202	Pr	P	housed at 18 °C; calorimetry	Holmes & McLean, 1974
385	128 – 202	Pr	NP	housed at 23 °C; calorimetry	Holmes & McLean, 1974
418	168 – 227	M	P	Assumed ME _m of 100 kcal	Verstegen, 1971

^a (kJ/ BW^{0.75}); ^b M=Multiparous; Pr= Primiparous ; ^c NP= Non-pregnant; P=Pregnant
* BW^{0.85}

We have recently completed experiments (Samuel et al 2007a,b,c,d), to re-evaluate the ME_m of sows that represent lines of pigs with high lean growth rate, and are highly prolific. Using the daily energy intakes and expenditures, and the formulae from Lodge et al (1979), ME_m was calculated. For sows fed at approximately maintenance energy requirements, 473 kJ/BW^{0.75}, the calculated ME_m was 515 ± 8 kJ/BW^{0.75}, and for sows fed at approximately 2 times maintenance energy requirement, 925 kJ/BW^{0.75}, the calculated ME_m was 495 ± 9 kJ/BW^{0.75}. These estimates of ME_m were not significantly different ($P=0.15$). The overall mean ME_m for these sows was 506 ± 7 kJ/BW^{0.75}.

The energy metabolism of sows is often expressed on the metabolic live weight basis with the standard exponent of 0.75. However, this may not be the most correct exponent due to the increase of lean tissue in modern breeds. Lean tissue requires more energy to maintain per kg than does lipid (Rivera-Ferre et al 2006). Increasing lean tissue content of the carcass increases the relative contribution of protein turnover to HP. In our recent experiment on pregnant sows (Samuel et al 2007d), the exponent was calculated to be 0.6116. This value is similar to the value of 0.60 previously proposed by Noblet et al (1991) for growing pigs. Both exponents were used to correct the HP for individual sow body weight in calculating the efficiency of energy utilization (k_{pf}). The k_{pf} using the exponent 0.6116 and 0.60 was 0.76 in both cases. This value for energy efficiency is similar to previous reports (Verstegen et al, 1971; Close et al, 1985; Noblet and Etienne, 1987). We propose that the exponent 0.60 should be used to express energy metabolism of sows on metabolic weight basis. Therefore, we calculated that the ME_m , using the k_{pf} value of 0.76, for this population of pregnant sows was 1018 ± 20 kJ/BW^{0.6}.

We conclude that the current NRC value for ME_m (444 kJ/kg BW^{0.75}) is too low for this population of sows by about 14%. This increase compared to NRC (1998) is similar to the 1% per year increase in heat production between 1984 and 2002 estimated by Brown-Brandl et al. (2004). Changes in energy requirements are probably due to a decline in backfat, i.e. increase in lean body mass, and an increase in protein turnover rate in sows. We conclude that because the efficiency of energy utilization affects the ME_m , that measurements of energy metabolism and efficiency of energy utilization also require further investigation. These redefined requirements for energy in cows should be reported with the correct exponent to enable accurate application of the recommendations across different body weights.

■ Protein and Amino Acid Requirements of Sows

Similar to the problem with energy, there are few estimates of amino acid requirements for sows derived from modern strains of pigs with high lean gain and highly prolific dam lines. There have been many estimates of lysine requirement of sows in the past but there are few recent estimates. The recommended daily lysine requirement of non-pregnant sows at maintenance, 36 mg/kg^{0.75} (NRC 1998), was estimated mainly from research from the 1960's through the 1980's with growing pigs and sows. We have recently measured maintenance lysine requirement of sows using indicator amino acid oxidation (Samuel et al 2008a). The dietary lysine requirement was calculated by regression analysis to be 49 mg/kg^{0.75}; this exceeds the current recommendation (NRC 1998) by 30%. HP and RQ were also measured during this experiment and these were lowest when sows received the intake of dietary lysine that was closest to our estimate of requirement. These data demonstrate that energy metabolism was also most efficient at this intake and therefore confirm via independent measures that the lysine requirement of these sows was much higher than the current NRC (1998) estimate.

There are very few estimates in sows for the requirements for the other amino acids. For example, the current NRC (1998) recommendation for methionine intake in gestating sows is based on an assumed ideal protein ratio for gestating sows because there are no direct estimates of methionine requirement in sows. If we apply the ideal protein ratio and use our new estimate of lysine requirement, the methionine requirement for maintenance of sows would be approximately 14 mg/kg^{0.75}, a 40% increase over the current recommendation. Methionine has many critically necessary functions during gestation, including methylation of DNA during development, which is important for regulation of genetic expression. Obviously, a direct estimate of methionine requirement in sows would be of considerable value in accurately formulating diets for highly prolific sows.

There are very few estimates of threonine requirement during gestation and only one in the last 10 years (Dourmad and Etienne 2002). The authors concluded that their estimate was greater than the NRC (1998) recommendations 'because of a higher daily N retention'. This agrees with our hypothesis that amino acid requirements of sows have increased because of higher lean body mass and increased rate of protein turnover. For lactation, recent estimates of threonine requirement vary by 30% from 5.2 g/kg (Cooper et al. 2001) to 6.9 g/kg (von Paulicks et al. 1998). Even greater variability exists for estimates of the valine requirement of lactating sows, for which there is currently no consensus. For example, Richert et al. (1996) estimated that the valine requirement was at least 115% of the lysine requirement, whereas Gaines et al. (2006) proposed a maximum of 86% of the lysine requirement. We believe that amino acid requirements of modern

lines of high performance sows should be systematically re-determined for maintenance, and during gestation and lactation.

■ Phase Feeding for Sows

Currently, most sow diets and feeding programs assume that amino acid and energy requirements are constant throughout gestation and lactation. Our research clearly demonstrates that requirements are not constant throughout gestation or lactation. The sow and litter body weight gain during gestation, increases the amino acid maintenance requirement as gestation progresses (McMillan et al 2003). Recently, Samuel et al. (2007a) found an increase in amino acid (leucine) oxidation during late gestation. This indicates that either the efficiency of amino acid utilization declined during late gestation, or that essential amino acids were being oxidized to make up for insufficient energy intake. Samuel et al. (2008b) showed that leucine oxidation increased significantly as lactation progressed, indicating that more protein was being catabolized, probably to provide additional energy. Therefore, the amino acid intake of these sows in late lactation was insufficient to meet the demands for both protein synthesis and energy utilization. These changes show that both energy and amino acid requirements need to be determined for different periods of gestation and lactation. These data also show that a meaningful reassessment of sow nutrition can only be achieved by concurrent determination of amino acid requirements and energy expenditure.

■ Conclusion

The productivity and performance of sows has changed greatly in the last 20 years as a result of genetic selection and improved management. However, our understanding of the nutrient requirements of sows has not kept pace with the increases in animal performance. Our recent research shows that the NRC (1998) recommendations are significant underestimates of the energy and amino acid requirements of the prolific sow. New and more accurate nutrient requirements for prolific sows will support continued increases in productivity and reduce the negative side effects of high prolificacy.

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