Recent Advances in the Nutrition of the High Producing Sow* - Review -

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ABSTRACT : Genetic advances, changes in housing systems and new management strategies have made it necessary to thoroughly review conventional nutritional programs. The approach has changed from one of feeding to permit gradual depletion of fat and protein tissues to one of feeding to maintain long-term nutritional balance. Increasingly the sow is viewed as a dynamic system that can be described by a mathematical model. There is opportunity to improve the initial models through research to provide a better understanding of metabolism and key physiological events in the sow's reproductive life. Direct experimentation remains a very important tool for defining nutritional requirements. Recent data supports increases in amino acid recommendations during lactation. Voluntary feed intake remains an intractable problem during lactation.
(Key Words: Sow, Nutrition, Lactation, Gestation, Amino Acids)

INTRODUCTION

The past two decades have seen a substantial change in the performance expected from the breeding sow. The average number of pigs born alive and weaned has increased by 9% and 14%, respectively (MLC, 1979, 1998). At the same time, the opportunity to recover from nutritional inadequacy during idle periods in the reproductive cycle has virtually disappeared as the weaning to breeding interval has been reduced to the biological minimum. One result has been an increased pressure on the nutritional program to precisely be adequate in each stage of the sow's productive life.

Conceptually, sow feeding is a simple process of balancing nutrient intake with the losses associated with maintaining life and supporting the reproductive process. But, under the surface it is an exceedingly complex and dynamic system that involves an intricately regulated flow of nutrients from diet to maternal tissue, conceptus and milk. At times during lactation the quantitative flux is quantitatively enormous and in the direction of milk output. However, within hours of weaning, milk synthesis is shut down and nutrient flow is shunted to recovery of maternal tissues in preparation for the subsequent pregnancy. Increasingly, nutritionists are engaged in constructing a comprehensive model as a basis for developing life-long feeding strategies.

In this paper we will begin with a brief review of the modeling effort and then turn to the experimental data that continues to serve as the primary guide to sow feeding.

MODELS

There have been several attempts to examine the sow systematically. Perhaps the most comprehensive to date is that described by Pettigrew et al. (1992a). The approach was to describe quantitatively the flow of primary energy-yielding nutrients and amino acids from their origin in the diet or in maternal tissue to their metabolic fate or output in milk. The model is complex and draws extensively on published data to assign values to rates of metabolic flux and product yield. The model has been evaluated by comparison of predicted values to empirically derived data (Pettigrew et al., 1992b). To our knowledge the model has not yet been used to develop feeding programs in a commercial setting.

Other approaches have been less reductionist. Whittemore (1996) used data from a comprehensive review of published literature to describe quantitative relationships between energy and protein status and reproductive success in primiparous sows. The report emphasizes the importance of both energy and protein nutrition in the long-term health of the sow. Our approach has been to focus on the dynamics of energy and amino acid exchange during lactation as a first step to understanding the more complex system.

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The model presented in figure 1 was described by Stein in his 1997 doctoral thesis at the University of Illinois. This model is of interest because it may be the first to acknowledge the role of obligatory catabolism in providing nutrients for maternal maintenance and milk synthesis. Obligatory catabolism occurs when tissues developed during pregnancy, i.e., the uterus, and lactation, i.e., the mammary gland, are broken down in the following stage of reproduction. This catabolism is physiologically dictated and the liberated nutrients must be accounted for in balance calculations.

The contribution of regressing organs to the amino acid supply available to the lactating sow is now a subject of investigation in our laboratory.

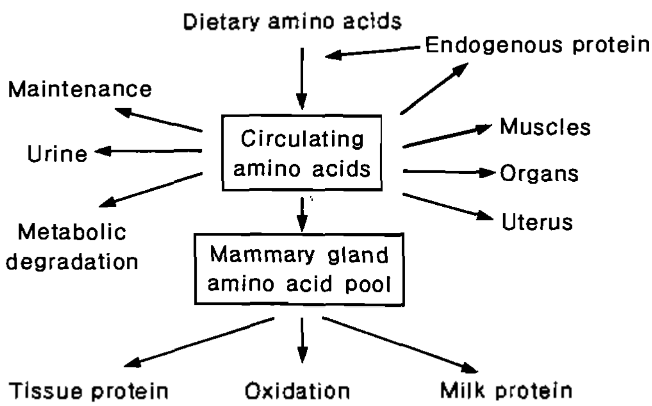

Figure 1. Amino acid flow in lactating sows.

The Stein model of lactation has prompted other questions as well. For example, King (1991), using efficiency data from Mullan et al. (1989) to calculate a dietary amino acid requirement based on amino acid output in milk. That model is logically correct but may not adequately address the mammary need of amino acids for glandular growth and maintenance. Trottier et al. (1997) have provided data on uptake of amino acids into the mammary gland. Additional work has been done recently to define the extent of glandular growth during the first 28 days of lactation. Our data (Kim et al., 1998a) suggest that glandular growth in early lactation is significant. It is also suggested that glandular growth is affected by protein and energy intake of the sow during lactation (Kim et al., 1998b).

The development of a fully functional model to describe the dynamic nutritional needs of the breeding sow remains to be accomplished.

BREEDING SOW NUTRITION-THE EXPERIMENTAL KNOWLEDGE

Classical feeding and metabolic experiments remain one the primary basis for examining nutritional questions. Progress has been slow given the variability inherent in sow performance data and the time required to conduct meaningful multi-parity experiments. The overwhelming effort has been given to energy and amino acid requirements and that will be the focus of the remainder of this review.

Energy

In a classical report, MacLain (1969) first described the 'thin sow syndrome'. The condition was characterized by massive maternal weight loss during lactation followed by failure to return promptly to estrus following weaning. In severe cases, the sow developed anorexia and progressively deteriorated. Energy nutrition continues to be extensively investigated.

The sow has an impressive capacity to mobilize body energy reserves to sustain milk production. The data (Roos, 1989) shown in table 1 are typical. Sows were either fed free-choice, about 18 Mcal of ME per day, or half that amount, about 9 Mcal per day. Diet formulation was such that protein, vitamin and mineral intakes were equal regardless of energy intake. Note that milk production and composition were unaffected by treatment. The mobilization of body fat stores is reflected in the massive weight loss by sows fed the low energy diet, the

Table 1. Effect of energy intake during Lactation on milk production and sow body composition[a]

Item	High energy[b]	Low energy[b]
No. sows	20	21
Average parity	4	4
Pigs weaned	8.29	7.76
21-day sow weight loss (kg)	−6.73	−19.20
Milk yield (kg/d)	5.18	5.13
Milk fat on day-14 (%)	7.22	8.50
Milk protein on day-14 (%)	57.8	55.0
Plasma free fatty acids on day-14 (mEq/l)	.03	.34
Plasma urea nitrogen on day-14 (mg/dl)	9.11	14.16
P_2 fat depth at weaning (cm)	1.69	.75
Liver weight at weaning (g)	2,515.9	2,275.32

[a] Roos (1989).
[b] Low energy and high energy were approximately 9 Mcal and 18 Mcal per day, respectively.

elevated levels of free fatty acid circulating in blood and the low amount of P_2 fat seen at weaning.

The most immediate consequence of loss of body tissue during lactation is an extended weaning to estrus interval (Reese et al., 1984, King and Williams, 1984). The effect on subsequent reproduction following eventual breeding is less clear but it is likely that ovulation (Hardy and Lodge, 1969) is also reduced. The early assumption was that there was a minimum level of body fat required for ovulation and that estrus would not occur until this had been recouped post-weaning.

Long-term depletion of body fat reserves is associated with reproductive failure (Young et al., 1990). Data from a recent Scottish experiment serve to illustrate this point (table 2). Some 240 genetically lean gilts were taken through three successive reproductive cycles while being fed either a conventional diet or a diet designed to promote the accretion of fat tissues - lower energy intake in gestation, followed by higher energy intake in lactation. The average weaning to estrus interval was reduced by five days after the first litter and four days after the second. More importantly, the number of sows culled was more than twice as great when the conventional regime was applied.

Table 2. Effect of different gestation and lactation energy levels on long term reproductive success[a]

Item	Conventional Energy Scheme	Fat-Promoting Energy Scheme
Energy intake (Mcal/day)		
1st Gestation/Lactation	7.40/15.17	6.93/16.73
2nd Gestation/Lactation	9.08/16.65	7.57/18.78
3rd Gestation/Lactation	9.22/16.87	7.79/18.1
Number of sows	120	120
Sow cullings after 3 litters	28	11
Culls for reproductive failure	13	4

[a] O'Dowd et al. (1997).

Physiological studies (Rozeboom et al., 1993) suggest that the rate of loss in fat tissue may be as important as the absolute quantity of fat in the body in the induction of post-weaning anestrus. This supports a hypothesis that the altered metabolic state associated with significant tissue catabolism acts to suppress hormonal changes required for the onset of ovulation.

Tokach et al. (1992) found that sows with a late return to estrus following low-energy intakes during lactation had altered profiles of circulating luteinizing hormone. These alterations occurred as early as day-14 in lactation. More recent work, (Koketsu et al., 1996) supports a role for insulin in mediating this response. Kirkwood and Thacker (1991), however, were unable to reduce days to estrus by exogenous insulin injection following weaning. This is not surprising in that it is likely that the hormonal events are established prior to weaning.

Insulin is clearly affected by fat status of the sow. Trottier (1995) fed diets to produce females with either 21 mm (control) or 28 mm (high energy) of backfat thickness just prior to parturition. Daily feed intake early in lactation by the obese gilts was significantly less than that of the controls resulting in significantly greater loss of body fat.

The obese pigs had clear difficulty in glucose clearance following bolus injection as indicated in figure 2 on day 112 of gestation. Feed intake by the obese gilts was 3.0 kg during the first week of lactation compared to 4.0 kg for the control animals. The fatter animals experienced rapid weight loss and by day-14 of lactation yielded a glucose clearance curve not unlike the control gilts.

In summary, it appears that over-feeding during gestation results in insulin resistance in early lactation leading to low appetite and excessive weight loss, a factor in delayed post-weaning return to estrus.

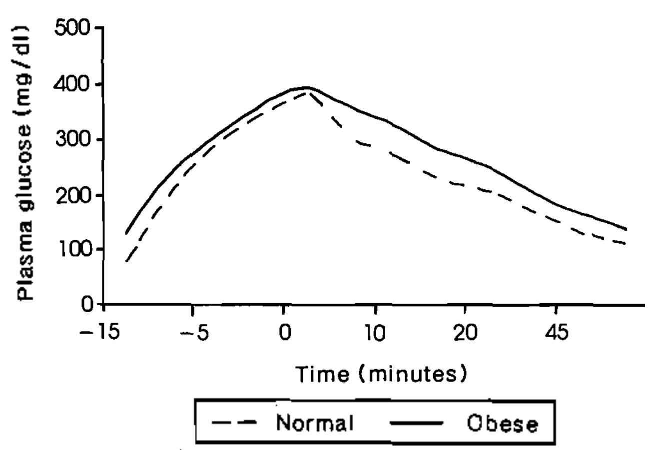

Figure 2. Glucose clearance in normal and obese sows on day 112 of gestation.

Protein and amino acids

The sow has a remarkable capacity to buffer her conceptus against dietary amino acid deficiencies during gestation. The point is vividly illustrated by work published by Pond et al. (1969) in which it was shown that gilts could be fed a diet essentially devoid of amino acids during gestation and still produce a viable litter of piglets. Piglets were small but viable. The ability of the sow to protect her developing piglets against nutritional deficiencies is limited. Mahan et al. (1977) fed gravid sows a corn diet supplemented only with vitamins and minerals for three successive pregnancies. Adequate diets were fed during lactation. It was only in the third reproductive cycle that the effects of an inadequate amino acid intake in pregnancy became evident. Given the buffering capacity of protein tissues, it should be apparent that accurate estimation of requirements during gestation is a difficult matter.

Most of the available data on amino acid requirements for the gestating sow are in reports of experiments conducted in the 1970s and early 1980s, c.f., Leonard and Speer (1983) and Easter and Baker (1977). Surprisingly little information has been added to the international literature in the past decade. Current knowledge is well summarized in the review by Pettigrew and Yang (1997).

The amino acid needs of the lactating sow have received much greater scrutiny. The primary focus has been on lysine, the first limiting amino acid in most diets. Work was stimulated by a popular article (King, 1991) wherein a factorial approach was used to predict a daily requirement for 52 grams of digestible lysine for a sow nursing a 10 pig litter. This estimate brought into question the NRC (1988) recommendation of 31.8 grams.

Coma et al. (1996) used a plasma urea nitrogen technique to determine the lysine requirement for mature sows. Based on regression analysis of the data, the authors estimated that an adult sow nursing 10 piglets requires at least 55.3 g/d of total lysine to minimize body protein mobilization. In a more comprehensive experiment, Dourmad et al. (1998) found that between 45 and 55 g/d of total dietary lysine is required for high-yielding sows. Other investigators, c.f., Knabe et al. (1996) have demonstrated the inadequacy of the NRC (1988) level but have not established an alternative requirement.

There has been interest in other amino acids. An experiment reported from the Kansas Experiment Station (Tokach et al., 1993) suggested a tendency ($p < .09$) for improved weaning weights when valine was added to a high lysine (.90%) diet. When considered on the basis of litter weaning weight, the effect was more evident ($p < .04$). A subsequent experiment (Richert et al., 1997) provided supportive evidence for an effect of valine supplementation on litter weaning weights. As in the previous experiment, there was no response to valine noted for sow weight change in lactation, backfat thickness or feed intake. The biological basis for this response is not clear. Careful review of the data in an earlier valine requirement study (Russelow and Speer, 1980) allows the suggestion that the requirement may have been underestimated.

Limited experimental are available for other amino acids. Pettigrew (1996) has proposed the application of an ideal protein concept to the estimation of requirements for threonine, methionine, methionine + cystine and tryptophan. This approach states the requirement for these amino acids as a percentage of the lysine requirement. The relationships proposed are shown in table 3.

Research on energy and amino acid needs of the modern breeding sow will undoubtedly accelerate in the next several years in parallel with genetic improvement.

Table 3. Proposed amino acid ratios for lactating sows[a] (Expressed as a percent of the lysine requirement)

Amino Acid	1.5 kg/d[b]	2.5 kg/d[b]
Lysine	100	100
Threonine	61	60
Methionine	25	26
Methionine + cystine	52	49
Tryptophan	20	19

[a] Pettigrew (1996).
[b] Litter growth rate.

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