Swine Nutrition Conference Proceedings

Indianapolis, Indiana — September 4, 2008

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Appreciation is expressed to the Indiana Farm Bureau and their staff for hosting the 2008 Midwest Swine Nutrition Conference and providing the facilities for this function.

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Nutritional Issues Facing the Swine Industry – Squeezing the Lemon

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Summary

Feed ingredient prices have increased dramatically during the last two years and we have likely reached a new plateau for major ingredient prices. We are now in a new environment relative to past feeding practices, priorities and paradigms. Optimizing grain micron size and pellet quality are opportunities in most production systems. Current descriptions of grain energy values at various grain micron sizes is limited and in some cases not considered in diet formulation. As past sources of feed energy become diverted more fully to other uses it becomes increasingly important that our methods focus on extracting every bit of value out of feed ingredients. An improved understanding of the feed and ingredient processing opportunities allows for optimization of nutritional strategies. Consistency in the current knowledge of the optimum methods for developing gilts with lifetime productivity in mind is lacking. Various nutritional and growth strategies have been proposed but need refinement and large scale verification. Additionally, sow lameness is becoming a recognized challenge for the swine industry. Sorting through the long list of potential reasons for lameness and addressing the nutritional component is an industry wide opportunity.

Introduction

At the time of this writing it is hard to focus on many challenges that rank above and beyond the challenge of cost effectively feeding a swine herd in an environment in which we have recently hit all time record prices for corn and soybeans. What looked to be difficult times as we approached 100% cost appreciation in corn during a 12 to 18 month time period became an enormously big challenge as we crossed into corn futures prices that have approached 350% increase over recent historical prices. For this discussion, I've chosen to concentrate on practical production implementation challenges, primarily focusing on identifying and discussing gaps in nutritional information that make it more difficult to correctly "squeeze the lemon" for feeding cost improvement. With this focus, "nutritional challenges", is expanded to include feeding practices and diet form and quality. All are important factors as we consider how we prepare, present and extract value from the feed that is consumed. Properly developing females destined to be part of our breeding herds is important. Consideration of the gilt development impact on lifetime productivity presents large opportunities for improvement. Potentially tied to gilt development is the rising challenge to reduce the incidence of lameness in our sow herd. In an ever increasing environment of concern about animal welfare, the opportunity for our industry to identify the primary causes and implement strategies for improvement are significant.

Grain Micron Size

Determining the optimum particle size for grain used in swine diets has many decision points. For example, depending on genetics, health of the herd, feeder type, grain processing equipment (i.e. roller mills or hammer mills) and in some cases opinion relating to potential ulceration problems with reduced micron size, the micron size target may differ. Many of the factors listed above are not well defined relative to the financial impact over a changing micron size of grain. However, the feeding value of corn at various micron sizes has been defined and presents itself as an opportunity for evaluation and cost improvement.

Wondra et al., 1992 evaluated the effect of micron size on pig performance and nutrient digestibility in finishing pigs from 56 to 115 kg of body weight. As shown in table 1, digestibility of dry matter, nitrogen and gross energy improved linearly ($P<.05$) as micron size was reduced. This impact, when related to potential improvement in feed conversion due to improved dry matter digestibility, results in reduced feeding cost. There is also a cost of processing corn to a smaller micron size. In table 2, the energy draw for grinding to various micron sizes is shown. I have applied a current cost per kWh and included in the table an estimate for the cost of grinding.

As would be expected, as costs of the ingredients increase, the value of improved utilization of the ingredient is increased. Listed in table 3 is an example of the value change due to micron size at two different prices of corn. The example diet is held constant in energy, with the addition of fat, as the corn energy changes due to micron size change. Utilizing fat as an ingredient and holding its price constant in value relative to corn (350%) allows for the expression of the value of the energy change due to micron size manipulation. The value, at $6.00/bu corn, of 600 vs 800 micron corn is approximately $2.79/ finishing pig fed. The cost of grinding, using even the extremes of 1,000 micron and 400 micron grinding costs, is only $.08/pig. Thus, the value in moving micron size lower based on these assumptions alone is tremendous.

A gap in the current methods used to describe the energy value of corn is the fact that very few if any references provide a benchmark to the micron size of the corn used as the energy value was derived. This may be looked at as insignificant as a 200 micron change in corn would only move metabolizable energy estimates by approximately 3%. However, with the black and white decision making properties of least cost formulation, an energy value change of this magnitude can mean inaccurate nutrient content of the final diet as well as incorrect purchasing decisions being made on alternative ingredients.

Pellet Quality

The debate about pellet quality and its importance or our opportunity to influence continues. Large, high volume feed mills are many times primarily focused on throughput. Once again, the value of this feed processing quality indicator has changed with rapidly changing ingredient prices. Cost of pelleting has also increased due to rising energy costs. It is important that we consider the value of pellet quality change in the context of other criteria and focus on optimizing the system rather than maximizing one certain component of the system.

Stark et. al, 1993 described the value of reducing feed fines presented to the pig through increased pellet durability/quality. Results of the study, shown in table 4, indicated that feed conversion increased linearly ($P<.1$) as the percentage of fines in the diet increased. The authors concluded from this study that at a level of approximately 20 to 25% fines the value of pelleting is significantly reduced. We conducted a study in Murphy Brown research facilities to evaluate this feed quality question. Our results are similar to that of Stark et. al. in that feed conversion deteriorated with increasing fines in the diet up to a plateau at approximately 50% fines.

Multiple considerations must be made when evaluating actions relating to feed milling and economics of pellet quality improvement. Factors to consider and apply to the pelleting value side of the equation are feed conversion and micron size opportunities as described above, increased opportunities for use of alternative ingredients as well as feed volume management for both manufacturing and delivery requirements. Costs of pelleting and potential changes in processes to improve the quality are considerations for the cost of pelleting. Understanding the value and costs associated with pelleting and optimizing the system is key to making the correct decision.

Gilt Development

Definition of effective gilt feeding programs that will promote maximum lifetime productivity of gilts entered into the herd is a significant need. Many different strategies have been proposed. Rate of growth, dietary nutrient requirements and desired final body composition are all areas needing further definition and present opportunities for refinement.

Results of a field study reported by Williams et al., 2005 (figure 1) show the impact over the first three parities of the weight that gilts receive their first service. Gilts bred at or below 135 kg body weight had fewer pigs born than gilts in other weight categories during the first three parities. Whether it be growing space, feeding program or other criteria that limit body weight accumulation, the impact of this measure alone will have a large impact on lifetime productivity.

An improved understanding of the benefits of using organic trace minerals to better prepare the gilt for depletion over time is of interest. The need for additional macro minerals for improved bone development and potentially reduced lameness in later years is established but refinement in estimate assumptions is needed in the increased cost competitive environment we are in. Genetics has played an important role in providing the opportunity for gilts entering the herd to have increased pigs born over her lifetime. It should not be a surprise that with this improvement in efficiency, modifications to nutrient requirements for both rearing and maintaining the gilt may have changed.

Sow Lameness

A challenge area for the industry was recently hilighted at a conference organized by Zinpro Corporation during which a realistic view of the opportunities the industry has to better understand the severity and impact that sow lameness has on sow productivity was discussed. Although this topic is multi-faceted in nature, one area for further exploration and refinement is the area of sow nutrition. Wilson and Ward, 2008 described the factors they see as primary factors for having some involvement in sow lameness (figure 2). Factors such as environment, management, genetics, nutrition and micro nutrients all are thought to have varying impact and are areas that require further exploration.

Barneveld and Vandepeer, 2008 reviewed the current understanding of the role of nutrition with respect to foot health. They summarized the nutritional component as being one that is somewhat understood relative to the impact of biotin but open for much improvement in understanding as other nutrients are considered. The main nutrients affecting foot health in pigs as reported by Barneveld and Vandepeer are the sulfur amino acids, calcium, zinc, copper, selenium, manganese and vitamins A, D, E and biotin.

Although this is a new area of emphasis, the potential impact to reduce sow mortality or turnover in the herd as well as increase our industry's level of animal welfare related sensitivity would both be very positive.

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Table 1. Effects of Particle Size on Performance of Finishing Pigs[ab]

	Micron Size			
	1,000	800	600	400
Apparent Digestibility, %				
Dry matter[c]	82.81	83.28	82.57	85.46
Nitrogen[c]	75.83	76.30	76.16	79.94
Gross energy[d]	82.54	82.82	82.34	85.96

[a] Adapted from Wondra et. al., 1992

[b] 160 pigs (2 pigs/pen and 10 pens/treatment) with an average initial weight of 56.8 kg and an average final weight of 115 kg.

[c] Linear effect of particle size reduction (P<.05)

[d] Linear effect of particle size reduction (P<.01)

Table 2. Milling Energy and Pellet Durability Across Various Corn Micron Size[a]

	Micron Size			
	1,000	800	600	400
Pellet durability	78.8	79.4	82.4	86.4
Milling energy, kWh/ton	2.42	2.78	3.46	7.35
Milling cost[b], $/ton	.194	.222	.278	.588

[a] Adapted from Wondra et. al., 1992

[b] Calculated at a cost of $.08/kWh

Table 3. Diet Costs at Various Corn Costs and Micron Size[a]

	Corn Cost, $/bu	
Corn Micron Size	3.00	6.00
400	164.04	255.85
600	169.72	266.36
800	175.12	276.33

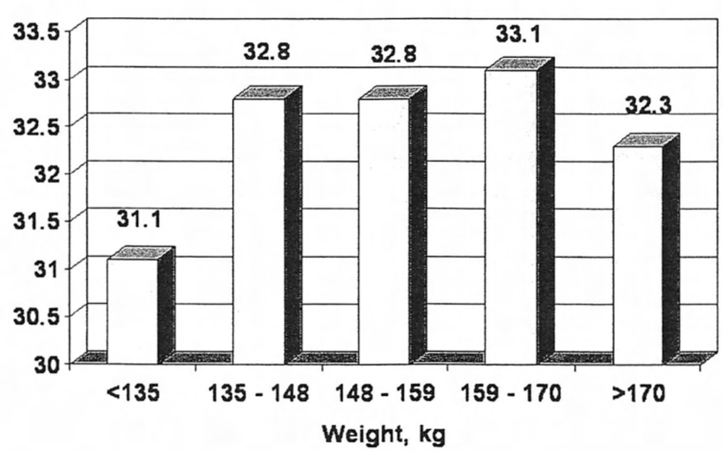
[a] Isocaloric diets using fat addition to standardize energy content and fat prices held at 350% that of corn.

Table 4. Effects of Pellet Fines on Growth Performance of Finishing Pigs[ab]

Item	Meal	Screened Pellets	Percentage Fines 20	40	60
ADG, kg	.932	.959	.959	.964	.941
ADFI, kg	2.59	2.54	2.66	2.67	2.66
F/G[c]	2.78	2.65	2.78	2.77	2.82

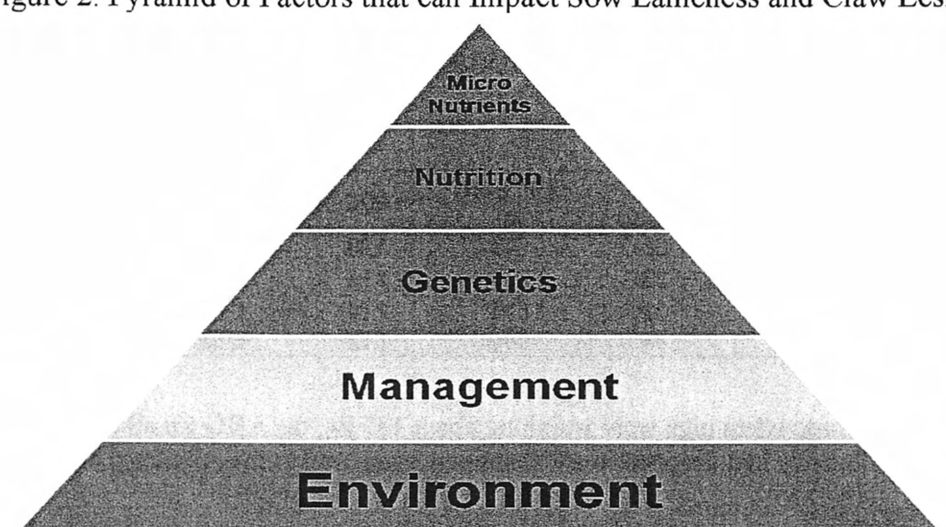
[a] Adapted from Stark et. al., 1993.
[b] Total of 80 pigs with an average initial body weight of 53.6 kg (2 pigs/pen and 8 pens/treatment).
[c] Linear effect of fines.

Figure 1. Impact of Weight at First Service on Total Born through 3 Parities



Williams et. al, 2005

Figure 2. Pyramid of Factors that can Impact Sow Lameness and Claw Lesions [a]



[a] Wilson and Ward, 2008

Successful Use of DDGS in Swine Diets

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Summary

The use of DDGS in swine diets is important since it provides energy, fiber, protein and available P. Our laboratory has shown that when diets are properly formulated the nutrient needs of the grow/finish pig can be met with as high as 20 to 30% DDGS in a corn/soybean meal diet. There is no negative impact on dressing percent and other carcass characteristics. Similarly, 15% can we used with corn and soybean meal in a lactation diet for highly productive sows.

Introduction

There is tremendous variety in the quality of the product called "DDGS" derived from corn not only because of the quality of the corn but the differences in production methods and quality control. Hence, not all DDGS will respond the same in diet formulation. Stein (2007) reminds us of the importance of digestible lysine which is reduced in DDGS when the product looses its yellow color due to high temperatures and the formation of Mailard products. Additionally, when comparing research results, it is important to notice if the energy:protein (lysine) are maintained across treatments. In this research, we have only used a high quality product that is visibly discernible because of its bright yellow color.

Grow-Finish

Because of the concern about soft fat when high oil diets are fed to finishing pigs and the bioavailability of DDGS P to meet their needs during these phases, we completed a 4 - treatment study using DDGS. With 0, 10, 20 and 30% DDGS in a three phase system and removal of DDGS 30 days prior to slaughter from the 20 and 30% diets, we evaluated growth performance and carcass characteristics. Crossbred pigs (n=308) were blocked by weight, sex and litter to the 4 treatments resulting in 7 replications of 11 pigs per pen. All diets contained phytase and 4% choice white grease and were isocaloric with wheat midds added to the 0 and 10% diets.

Phase 1 – Pigs were not gradually transitioned to these diets. Hence, those fed the 30% DDGS diets were suddenly fed a greater percent of fiber than in their previous diet. This resulted in lower ADFI and ADG during this first phase. Feed efficiency for pigs fed 30% DDGS during phase 1 was the same as that of pigs fed 0% DDGS (control).

Trt	Initial Wt. lb.	Mean Wt. lb.	Days on feed	Pen gain lb.	ADG	FI, lb.	ADFI	G/F
0%	66	125	33	643	1.83	1342	3.8	0.48
10%	66	125	33	651	1.86	1273	3.62	0.51
20%	66	126	33	636	1.84	1284	3.71	0.50
30%	66	122	33	604	1.72	1268	3.69	0.48

Phase 2- During this phase when pigs were weighing about 185 lb., the ADG for all treatments exceeded 2.0. As expected, feed efficiency had dropped in all treatments compared to the efficiency of the pigs during phase 1.

Phase 2

Trt.	Mean wt. lb.	d on feed	Pen gain,lb.	ADG, lb.	FI/pen, lb.	ADFI, lb.	G/F
0%	187	31	689	2.08	1848	5.57	0.37
10%	190	31	684	2.11	1730	5.34	0.40
20%	187	31	661	2.06	1743	5.44	0.38
30%	185	31	700	2.11	1742	5.22	0.41

Phase 3 – During this phase, the pigs in all treatments continued to exceed over 2.0 lb. per day (ADG) with reduced feed efficiency. The mean weight of pigs in phase 3 was about 255 lb.

Phase 3

Trt.	Mean wt., lb.	d on feed	Gain/pen, lb.	ADG, lb.	Feed/pen, lb.	ADFI	G/F
0%	255	33	745	2.03	2384	6.54	0.31
10%	257	33	724	2.03	2261	6.35	0.32
20%	257	33	741	2.08	2401	6.76	0.31
30%	257	33	787	2.17	2487	6.81	0.32

Overall Growth Performance –For this 97- day study, the ADG for pigs in all treatments exceeded 1.9 lb. with pigs fed DDGS having a G/F of 0.39 or 0.38. These results indicate that excellent growth performance can be achieved with up to 30% DDGS in swine grow-finish diets.

Overall Performance

Trt	d on feed	Gain/pen lb.	ADG, lb.	FI/pen, lb.	ADFI	G/F
0%	97	2077	1.94	5542	5.19	0.37
10%	97	2044	1.96	5279	5.01	0.39
20%	97	2038	1.93	5432	5.15	0.38
30%	97	2091	1.95	5471	5.12	0.38

Carcass – One pig per pen (n=28) was killed at the MSU Meat Laboratory.

Hot carcass weight, backfat, loin eye area and gut weight were determined. A fat sample was collected from the jowl for determination of iodine number and fatty acid analysis. Belly bar firmness was determined, and the belly was ground and freeze dried for proximate analysis. Pigs were individually weighed and commercially slaughtered for HCW (n=245). The dressing percent was 75, 75, 75 and 76 %. Hence, when diets are properly balanced for energy and protein (Lysine), the animal's dressing percent is not affected by DDGS as previously noted by Stein (2007).

Lactation

As we previously reported (Hill et al., 2007), high quality DDGS can be a source of energy, fiber, available P and protein for productive sows.

Fatty Acid Analysis - DDGS Grow-Finish Study

Fatty Acid Profile **(Expressed as Percent of Total Fat)**	**0% Mean**	**10% Mean**	**20% Mean**	**30% Mean**
Myristoleic (14:1)	1.19	1.15	1.14	1.00
Palmitoleic (16:1)	20.21	20.02	19.93	18.91
(17:0)	2.52	2.27	2.26	1.94
(17:1)	0.37	0.32	0.33	0.27
Stearic (18:0)	0.37	0.32	0.32	0.27
Elaidic (18:1*t9*)	9.52	9.41	9.33	9.71
Oleic (18:1*n9*)	0.43	0.36	0.38	0.34
Vaccenic (18:1*n7*)	46.72	45.59	44.10	45.86
Arachidic (20:0)	12.87	15.42	16.64	17.31
(20:1n9)	0.68	0.69	0.71	0.67
(20:3 T3)	0.11	0.12	0.10	0.12
Arachidonic (20:4*n6*)	0.13	0.13	0.13	0.13
Docosanoic (22:0)	0.78	0.92	0.93	1.04
Erucic (22:1*n9*)	0.28	0.32	0.31	0.30
(22:5 T3; DPA)	0.13	0.15	0.15	0.15
(22:6 T3; DHA)	0.08	0.08	0.06	0.05

Experiment 1 - Unlike with our grow-finish studies, sows were gradually transitioned to their lactation diets from 110 days of gestation. Sows (n = 61) were assigned to diets based on genetics, parity and farrowing date. The diets were isonitrogenous (21% CP, 1.2% Lys) and isophosphorus (0.8% P). Our objective was to determine if diets containing DDGS would have adequate energy to support the lactation of a highly productive sow. With equal amounts of fiber, the dietary treatments were (1) a corn and soybean meal diet with 5% beet pulp or (2) a corn and soybean meal with 15% DDGS. On day 2 of lactation, litters were balanced to achieve 11 pigs/litter, and the sows and their litters were weighed at day 2 and 18 of lactation. Fecal grab samples were collected from the sows at day 7, 14 and 18 of lactation.

Parameter	**5% Beet Pulp**	**15% DDGS**
Litter gain, lb.	92	95
No. pigs weaned	10.9	10.8
Sow weight loss, lb.	14	18
Gain/pig during lactation, lb.	8.4	8.6
Fecal P, ppm (DM basis) d 14	32.8	28.3

The data clearly shows that high quality DDGS will support lactation performance in highly productive sows.

Experiment 2 – With the extensive use of phytase in U.S. swine diets, it was essential that we determine how the highly available P in DDGS would interact with phytase. Thus, 87 sows were allotted as in Experiment 1 to 4 dietary treatments (1) corn and soybean meal(CON), (2) CON plus 227 FTU/lb. Natuphos, (CONP), (3) 15% DDGS, or (4) 15% DDGS +Phytase (DDGSP).

Parameter	CON	CONP	15% DDGS	15% DDGSP
Litter gain, lb.	101	102	93	93
No. pigs weaned	11	10.9	10.8	11
Sow weight loss, lb.	18	16	16	14
Gain/pig lb.	9	9	8	9
Fecal P,d18	33	33	29	31

Again, using 15% high quality DDGS in sow lactation diets provides the necessary nutrients to support an excellent lactation with minimal sow weight loss. Phytate P is reduced by the processing of corn to DDGS and further reduced by the addition of phytase. Hence, in this time of high feed costs, DDGS plus phytase can reduce the cost of P in the diet.

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Tools to Cope with Current Economics

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Summary

During periods of high production costs, such as those we are experiencing today due to rising costs of feed inputs and fuel, it is important for pork producers to adopt practices and strategies that lower cost of gain without sacrificing animal performance. Because feed costs make up the largest percentage of the cost of production, those strategies that improve feed conversion will provide the greatest opportunity for lowering the total cost of production. Now more than ever, a reexamination of dietary nutrient levels relative to the animal's actual nutrient needs is warranted. Things to include in this examination are lean gain potential, number of diet phases to use and the feed budget for each diet, split sex feeding, and the possibility of removing certain nutrients from the diet during the last portion of the finishing period. Diet preparation should also be carefully scrutinized to ensure improvements in efficiency aren't being left on the table. Changing feed particle size and pelleting of diets might offer potential for improving the utilization of nutrients contained in the diet. The weight at which pigs are marketed should be reevaluated to make certain return is being maximized. Alternative ingredients might offer a way to lower diet cost without sacrificing growth and efficiency of gain. Also, minimizing feed wastage provides a tremendous opportunity to lower cost of gain. An examination of equipment used to store, weigh, mix, deliver, and present feed to pigs should be conducted to make sure expensive feed is not being lost during each of these processes.

Introduction

Pork producers are currently facing a period of very high feed and production costs. Escalating prices for corn, soybean meal, dicalcium phosphate, and other feed inputs, as well as fuel costs for fabricating diets, heating animal facilities, and transporting animals, have pushed breakeven costs to levels that have made it extremely challenging for producers to remain profitable. While pork producers should always be looking for ways to improve production efficiencies and reduce input costs, it is vital during such periods as we are experiencing today. As is most often the case, there likely is not a single "silver bullet" that every producer can employ to get their bottom line back into the black. However, there are several options that should be on the table for consideration to help lessen the impact of today's high input costs without sacrificing animal performance. Since feed costs have the greatest influence on cost of production, adoption of factors that improve feed efficiency will have the greatest impact on profitability. Factors that will be discussed here include: (1) more precise matching of dietary nutrient levels to the animal's nutrient needs, (2) use of appropriate diet fabrication methods, (3), use of alternative ingredients, (4) marketing animals at the most profitable market weight, and (5) minimizing feed wastage.

Dietary Nutrient Levels

When it comes to dietary nutrient levels that are needed to support pig growth and performance, there is not a one-size-fits-all. There are several factors that must be considered to avoid under-feeding nutrients and limiting an animal's ability to grow and perform at an optimal level, and to avoid over-feeding nutrients and unnecessarily spending too much on feed.

Nutrient Requirements vs. Nutrient Allowances

The National Research Council (NRC) periodically publishes a summary of recent research findings entitled *Nutrient Requirements for Swine*, which is the basis for many nutrient recommendations. The NRC presents percents and amounts of dietary nutrients required to achieve listed growth rates, feed conversions and reproductive levels when corn-soybean meal diets are fed under ideal conditions. These **nutrient requirements** represent minimum levels and do not include any surpluses. Consequently, nutrient levels recommended by nutritionists are **nutrient allowances**, which include a "margin of safety" over NRC levels.

During time periods when the costs of various feed ingredients are relatively low, nutritionist will often formulate diets with a fairly substantial "margin of safety" for certain nutrients (such as energy, P, Ca, and lysine). However, at today's high costs for corn, soybean meal, dicalcium phosphate, and other feed inputs, the target nutrient levels in diets should be examined to make sure they are meeting the animal's needs without too much excess to avoid paying too much for feed.

Lean Gain Potential

Increased selection for lean gain over the last two decades has led to substantial improvements in lean pork production and has opened the door for the development and refinement of nutrient requirements based on an animal's genetic potential for protein deposition. Despite these improvements, there is still tremendous variation in lean gain potential among different breeds and lines of pigs. It is intuitive that a fast growing animal with a high lean gain potential will have a higher amino acid need than a slow growing, fat animal. While most publications that provide nutrient requirements for pigs list nutrient needs for pigs of different lean gain potentials, without some knowledge of a given set of pigs' genetic capabilities for depositing protein it will be difficult to avoid overfeeding or underfeeding expensive nutrients.

Effect of Feed Intake

One of the biggest challenges for nutritionists in formulating diets, particularly for growing-finishing pigs, is obtaining an accurate estimate of feed intake. Once the daily nutrient requirements of an animal have been established, an accurate estimate of feed intake is needed to determine the optimal level of nutrients in the diet. Since feed intake varies largely between different farms and with the season, factors that affect feed intake should be monitored closely. Some of the major factors affecting feed intake include genetics, effective environmental temperature, health status, and feed quality.

Numerous studies have demonstrated the clear effects genotype of the animal can have on feed intake. For example, Schinckel (1994) observed that growing-finishing pigs of different genotypes managed under the same conditions and fed the same diets had variations in feed intake as high as 20-30% (Table 1). It is also worth noting from this study that differences in feed intake between barrows and gilts are not the same for all genotypes. Studies like this one clearly demonstrate that it is too simple to assume that there is one general feed intake curve that can be used to develop feed budgets for the varied genotypes raised in different production facilities.

The effective environmental temperature will also influence feed intake of pigs. During the summer months when temperatures are higher, it is typical to observe lower feed intakes as compared to those observed during cooler time periods. In general, for every 2° F rise in temperature feed intake will decrease by approximately 2% in weight. This explains why many nutritionists recommend more nutrient dense diets during the hot summer months to maintain nutrient intakes at desired levels.

Health status of the pig will also influence feed intake. De Lange and Baidoo (2007) found that pigs from different farms that were comingled at weaning had reduced feed intake and performance up through market weight when compared to high health status pigs of similar genotype (Table 2). This study highlights the fact that pigs with a challenged health status will consume less feed and grow slower and less efficiently than those with a higher health status. Reductions in feed intake and animal performance can occur in the absence of outward signs of disease.

The quality of the feed provided to pigs can also influence feed intake. Some of the factors related to feed quality that can affect feed intake include:

(1) Energy density of the diet – Pigs will typically consume less of an energy dense diet than one that is lower in energy. When high energy feed ingredients, such as fat, are included in a diet, it may

be necessary to increase the concentration of some nutrients to account for the anticipated reduction in feed intake.

(2) Freshness of the feed – Pigs will consume less of a diet that has become stale compared to one that is fresh and more palatable.

(3) Presence of mycotoxins – Mycotoxins are compounds produced by molds that when consumed by pigs will cause toxicity. The presence of certain levels of mycotoxins, such as deoxynivalenol (vomitoxin), fumonisons, and ergot, can reduce feed intake. In the case of deoxynivalenol, levels as low as 5 to 10 ppm can reduce feed intake by 25-50%, and levels of 20 ppm or higher can result in complete feed refusal.

Phase-Feeding and Feed Budgets

Phase feeding involves feeding a number of successive diets, each differing in nutrient content to accommodate the pattern of lean growth and feed intake of different age or weight groups of pigs. The benefits include a progressive reduction in diet costs, fewer nutrients excreted, and a potential improvement in feed efficiency. A feed budget simply outlines the amount of each diet that will be fed to move the pig from one weight class to the next.

It stands to reason that the more diets (phases) one is able to feed to pigs as they grow the closer one will be able to match nutrient needs with dietary nutrient levels. However, several factors must be considered when determining the optimal number of diets to use. These include:

(1) The incremental savings that can be realized with phase feeding decreases fairly rapidly as more diet changes are added (Table 3). For example, while each successive increase in the number of diets fed to grow-finish pigs results in a reduction in the total feed cost per pig, that largest incremental savings occurs when one goes from a 2 diet phase feeding strategy to one with 3 diets. When determining the optimal number of diet phases, the anticipated savings associated with more diet additions (reduced feed costs per pig, improvements in feed efficiency, improved carcass traits, etc.) should be compared to any added costs (purchase and installation of additional feed bins and/or additional feed delivery systems, labor associated with mixing and handling additional diets, etc.) that will result from the added diets.

(2) Does the operation's production schedule and pig flow allow animals of the same age to be grouped together for feeding? One should always keep in mind that diet nutrient levels are typically designed to meet the needs of the average pig in the group. The wider the age variation within the group, the more difficult it becomes to determine the optimal nutrient levels, regardless of the number of diets fed. Ideally, there should be no more than a 7 day age spread with a feeding group. Additionally, the smaller the group size the more challenging it becomes to adopt a phase feeding program that consists of more than three to four diets. Smaller group sizes translate to fewer pounds of each diet that will be needed. Some mills may not want to mix and deliver small loads of feed at a reasonable price.

(3) The tolerance, or accuracy, level of the feed mixing equipment should also be considered when choosing the number of diet phases to use. As more diet phases are added, the reduction in nutrient levels from one diet to next gets successively smaller. If the desired reduction in nutrient levels is smaller than the tolerance level of the feed mixing equipment, the chances of achieving the target nutrient levels in the diet are greatly diminished.

(4) Individual ingredients that will make up the complete diet should be analyzed periodically to determine their nutrient content. While "book values" of nutrient content for a wide variety of feed ingredients can be easily obtained, they may not reflect the actual nutrient composition of your ingredients. Cromwell et al. (1999) conducted a study to determine the variability in nutrient composition of corn and soybean meal from 16 different sources (obtained from 15 predominantly Midwestern states). These authors found that the nutrient composition of both corn and soybean meal varied among sources. For corn, the crude protein was found to range from 7.31% to 9.06% and the lysine content was found to range from 0.25% to 0.30 % (Figure 1). Similar variability was found in the Ca and P content of the corn sources. For conventional solvent-extracted soybean meal with hulls, the crude protein and lysine content ranged 42.8% to 44.6% and 2.76 to 2.89%, respectively (Figure 2). For solvent-extracted, dehulled soybean meal, the crude protein and lysine content ranged 46.1% to 49.3% and 2.85 to 3.17%, respectively (Figure 3). These results highlight the importance of obtaining an accurate analysis of the nutrient composition of the feedstuffs that will make up the diet.

When implementing phase feeding, it is vital that a feed budget be developed so that the appropriate amount of each diet is delivered to each group of pigs. Over-budgeting of a diet will increase costs and lead to overfeeding nutrients. Under-budgeting can limit animal performance due to a deficiency of nutrients. Ideally, each operation should develop a customized feed budget that is based on their animal's cumulative feed intake up to market weight. This allows differences among operations in terms of specific feeding programs, animal genetics, facilities, and management factors to be taken into account. A procedure for developing a customized feed budget for a specific swine operation can be found in the Kansas State University Swine Nutrition Guide, Growing-Finishing Pig Recommendations (2007).

Split-Sex Feeding

For some producers, split-sex feeding may offer the potential of improved nutrient use and reduced diet costs. If fed a similar diet, it is typical for gilts, as compared to barrows, to make more efficient use of feed, take in a smaller amount of feed, and have a higher percentage of lean (Patience et al., 1995; Table 4). Generally, the differences in performance between the two sexes grow more pronounced as the pigs grow heavier. These factors provide the basis for feeding barrows and gilts separately, with gilts receiving a more nutrient-dense diet. However, the widespread adoption of split-sex feeding across the swine industry has not been observed. According to a recent study conducted by U.S. Department of Agriculture, Animal Plant Health Inspection Service, Veterinary Services (USDA APHIS VS, 2007), only 9.3% of producers utilize split-sex feeding in the nursery phase, and only 29.6% of producers utilize split-sex feeding in the grower-finisher phase. The limited use of split-sex feeding in the nursery is not surprising since the greatest benefit of this strategy is observed in the grower-finisher phase.

When determining if the adoption of split-sex feeding will be of benefit for a particular operation, there are a couple of key issues to consider. First, if the group size of pigs is not large enough to fill a complete room or building (or at least one side of a room or building), the cost of extra feed bins and feed lines to store and deliver separate diets might not make split-sex feeding economically feasible. Second, if the age spread within a group of pigs is over 7 days of age, it would be more economical to focus efforts on minimizing the age spread rather than housing and feeding the sexes separately.

Nutrient Deletion

The concept of removing certain dietary ingredients and/or expensive nutrients for a period of time before slaughter to reduce the total feed cost has been evaluated for many years, but has only experienced limited use. But as feed input prices have continued to climb there has been renewed interest among pork producers to consider nutrient deletion (or at least nutrient reductions) during the final few weeks of feeding prior to slaughter. The most common dietary ingredients that are considered for possible deletion are vitamin premixes, trace mineral premises, and the inorganic phosphate source. The question of importance when considering nutrient deletion is how long before slaughter can a nutrient (or nutrients) be removed without negatively impacted animal performance and other traits of importance.

Shaw et al. (2002) reported that completely removing the dietary vitamin and trace mineral premixes, as well as removing two-thirds of the dietary inorganic phosphorus, for the final 28 days before slaughter did not affect growth performance or carcass traits (Table 5). This agrees well with previous work (Kim et al., 1997; Mavromichalis et al., 1999; McGlone, 2000) where removing the vitamin and trace mineral premixes from diets for finishing pigs for the final 3 to 6 weeks before slaughter did not affect pig growth and/or carcass characteristics. It has also been reported that growth performance and carcass characteristics is maintained at sufficient levels following removal of two-thirds or more of the dietary inorganic phosphate during the late finishing phase (O'Quinn et al., 1997; Mavromichalis et al., 1999). Additionally, Lindemann et al. (1995) found that pigs performed well with complete removal of dicalcium phosphate for the final 90 lb of the finisher period. However, these authors observed a decrease in loin eye area with complete removal of dicalcium phosphate.

If certain nutrients are removed for a period time before slaughter one would expect the excretion of those nutrients to be decreased, as well as the stores of those nutrients within the pig's body to be reduced. Results from van de Ligt et al. (1997) suggest that removing a portion of inorganic phosphate from the finishing diet negatively impacted P absorption, P retention, and bone breaking strength. Shaw et al. (2002) found that the removal of the supplemental vitamins and trace minerals along with removal of two-thirds of the dietary inorganic phosphate for 28 days preslaughter decreased fecal concentrations of

Ca, P, Fe, Mn, and Zn, and also decreased the concentrations of riboflavin, niacin, and P in the longissimus dorci muscle. Shaw et al. (2006) observed that complete removal of the vitamin and trace mineral premixes and removal of two-thirds of the dietary inorganic phosphate resulted in increased bone turnover (increased serum osteocalcin and pyridonoline concentrations, indicating an increase in osteblast activity and bone resorption) and decreased bone quality (decreased bone mineral density, and decreased bone strength). However, these negative influences on bone turnover and bone quality did not lead to a greater incidence of bone fractures at slaughter.

Taken as a whole, most of the available research would suggest that vitamin premix, trace mineral premix, and at least two thirds of the dietary inorganic phosphate can be removed from finishing pig diets for up to 4-6 weeks before slaughter with little effect on growth performance and carcass characteristics. However, because of the reduction in stores of the these nutrients in the animal's body and the reductions in bone quality, deletion of vitamin premixes, trace mineral premixes, and the dietary inorganic phosphate during the late finishing period should be limited to those animals that will solely be sold for slaughter. Nutrient deletion is not recommended for gilts that will be retained in the herd as replacements.

Diet Fabrication

Particle Size

It has long been known that particle size of the feed has a major impact on feed efficiency and apparent digestibility of dry matter, nitrogen, and energy (Wondra et al., 1995), with smaller particle sizes being more advantageous for these parameters. This is due to the fact that particle size reduction increases the surface area of the feed, allowing for a greater interaction of digestive enzymes and, therefore, better digestion and utilization of nutrients. However, producing smaller particle sizes requires greater energy inputs for milling and reduces the production rate of milling. Finer particle sizes also increase the incidence of gastric ulcers in pigs, increases dustiness, and decreases feed flowability (more bridging of feed in feeders). Based on pig performance and these other factors related to particle size, it is generally recommended that swine diets should have a particle size of between 600-800 μm (microns). However, if the proportions of "fines" (extremely fine particles) which are thought to be largely responsible for the increased incidence of ulcers can be limited, particle sizes of down to 400 microns might be of additional value to growing pigs provided flowability can be managed.

Despite this knowledge, there is still a broad range of particle sizes from farm to farm. In a survey involving over 2,500 feed samples collected between 1986 and 1992 at Kansas State University (Goodband et al., 1995), only 25.8% of the samples fell between 400-799 microns, with remainder of the samples being greater than 800 microns. These authors suggested that producers were possibly losing between 3 to 8 percent of their feed utilization costs because of feed that was ground too coarsely. Typically, every 100 micron reduction in particle size of a feed to the optimum range will result in an approximately 1.2% improvement in feed efficiency (about 7 lb of feed less per finishing pig).

Pelleting Diets

Pelleting swine diets will improve feed handling and animal performance. Wondra et al. (1992) noted an 8.8% improvement in growth rate and a 5.2% improvement in feed efficiency for finishing pigs fed a corn-based pelleted diet compared to those fed a meal diet (Table 6). This is in agreement with various other studies which show an improvement of 3 to 10% in growth rate and feed efficiency for pigs fed a pelleted diet compared to a meal diet. These improvements are believed to be due to reduced feed wastage and perhaps improved digestibility.

Pelleting appears to improve performance to greater extent with more fibrous feeds. Therefore, one expect greater benefits from pelleting a barley-based diet as compared to a corn based diet. This agrees with work reported by Patience et al. (1995) at the Prairie Swine Centre who observed that finishing pigs fed a canola and barley or canola and barley-wheat diet that was pelleted had a 19.2% improvement in growth and a 9.3% improvement in feed efficiency compared to those fed these diets in meal form (Table 7).

Pelleting does increase the total cost of a diet, so the added cost must be compared to the expected efficiency gains to determine if pelleting a diet will be economically beneficial.

On-Farm Feed Mixing Quality Control

If preparation of feeds fed to animals is done on the farm, whether it is done through a portable grinder-mixer or an elaborate feed mill, a quality control program for feed mixing needs to be in place to ensure your diets are blended properly. Errors in mixing that throw off nutrient levels by as little as 5-10% can lead to significant losses in animal performance, perhaps as high as $2-$5 per pig. A good quality control program should include the following:

(1) Regular maintenance and calibration of the equipment used to weigh and (or) meter ingredients. As a minimum, scales and metering devices should be checked and serviced at least twice per year.

(2) Regular maintenance of equipment used to process feed ingredients. Hammers in a hammer mill should be rotated or replaced as needed to ensure a consistent particle size. If a roller mill is used, make sure the rollers are properly maintained to achieve the desired particle size.

(3) Regular maintenance and monitoring of the mixing equipment to ensure the proper distribution of nutrients in the entire volume of the complete feed.

(4) Regular, scheduled analysis of feed ingredients and complete diets. Make sure a good representative sample is obtained to ensure an accurate analysis.

Use of Alternative Ingredients

With the dramatic rise in the price of corn, soybean meal, dicalcium phosphate, and other more commonly used ingredients in swine diets many producers are exploring the use of alternative ingredients. While inclusion of alternative ingredients may provide an opportunity to reduce diet costs, there are a few questions that should be considered before they are incorporated into swine diets.

(1) Is the nutrient composition of the alternative ingredient suitable for swine feeding? To be of an effective substitute for more commonly used ingredients the alternative must be an effective source of available nutrients or energy.

(2) Does the alternative ingredient contain any growth inhibiting factors or toxic substances that would restrict animal performance or cause health concerns? If present, unless these factors can be eliminated or neutralized inexpensively, the alternative ingredient should not be used.

(3) Is the value of the alternative ingredient greater than the cost of its inclusion into the diet? The major costs in swine diets are those ingredients that provide energy, protein (lysine), and phosphorus. Because of this fact, an alternative ingredient will need to provide one of these nutrients at a cost that is competitive to the more traditional ingredients (grain, soybean meal, dicalcium phosphate). If the alternative does not replace a portion of these more typically used ingredients at a lower price it should not be used.

(4) Are there any added costs associated with using the alternative ingredient? Some alternative ingredients look promising when only the cost of the ingredient is evaluated, but when freight costs for delivery, additional storage for the ingredient, additional processing equipment, and added labor for its use are considered it becomes more expensive to use than the traditional ingredient. All costs associated with the use of an alternative ingredient must be evaluated when determining its true cost.

(5) Is the availability and quality of the alternative ingredient sufficiently consistent to support its long term use? Unless a steady supply of the alternative ingredient, at a cost competitive price, and uniform quality is available, it should not be considered for use.

For information on a wide variety of additional alternative ingredients the readers can refer to a publication in the Pork Industry Handbook entitled *By-Products in Swine Diets* (PIH-108).

Optimal Market Weights

With the current high feed costs, choosing an optimal market weight for pigs has become even more critical to profitability. Although packers may still be requesting heavier market weight hogs, the cost for continuing to feed pigs to heavier weights deserves careful attention.

A simple economic principle is that the most profitable weight at which to sell market pigs is when the cost of adding the next pound of weight is equal to the revenue of that pound of weight. While this is a simple, straightforward concept, it is much more complicated in actual practice. The actual cost of adding additional weight will vary as feed prices change, and the additional weight can impact lean premiums and whether you are within the packer's preferred weight range to avoid sort loss (discounts for being over or under the preferred range of weights). Some animals can grow efficiently to heavier weights before enough fat is deposited to move it beyond the packer's preferred lean yield, while others will quickly become too fat and receive heavy discounts.

A spreadsheet calculator has been developed (Lawrence, 2008) to help producers determine the market weight that is best for their herd. This calculator allows producers to input their own specific data to evaluate the effects of feeding pigs for additional days (adding additional weight). Table 8 illustrates the effect on expected change in return ($/head) for feeding pigs weighing 240 lb an additional 7 days. Based on the assumptions shown in Table 8, a positive return would be expected from feeding 240 lb pigs an additional 7 days at feed prices up to $0.12 per lb as long as there was no deduction in packer premium. But if feed costs rise beyond $0.12 per lb a loss in return would be expected, even without any reduction in packer premium. If feeding a 240 lb pig an additional 7 days would result in a $0.50 reduction in packer premium (either through sort loss or a percent lean discount), a positive return would only be expected with feed prices up to $0.11 per lb.

Williams et al. (2008; unpublished data from PIC; Table 9) evaluated the optimal market weights for PIC327 barrows and gilts at four different feed prices ($0.06, $0.08, $0.10, and $0.12 per lb) when marketed to two different packers (Hormel and Tyson). For pigs marketed at Hormel, as feed prices increased from $0.06 to $0.12 per lb the market weight that resulted in the largest return decreased from 286 to 275 lb for barrows and from 285 to 278 lb for gilts. For those pigs marketed at Tyson, as feed prices increased from $0.06 to $0.12 per lb the optimal market weight decreased from 290 to 282 lb for barrows and from 290 to 284 lb for gilts.

It is clear that as feed prices rise, the market weight that will maximize return declines. However, a producer must carefully evaluate their packer's pricing structure as well as their own cost of gain to determine their optimal market weight.

Minimizing Feed Wastage

At today's feed prices, feed wastage can have a significant impact on the feed cost per pig (Table 10). In fact, keeping feed wastage to minimum could be the difference between making a profit and incurring a loss. Some of the major factors that can influence feed wastage include loss of feed through the production and delivery system, feeder design, and feeder adjustment.

Feed Production and Delivery System

On many farms, significant amounts of ingredients and feed are lost during the manufacture, storage, and delivery of feed to the animals. Losses that occur during these stages may include dust, moisture loss, spillage, cleanout material, spoilage, and rodent, bird, or insect damage. The following are some management practices that can help minimize losses as feed is fabricated, stored, and transported to feeders.

(1) Delay grinding ingredients until just before use and minimize storage time to reduce moisture losses.

(2) Check and immediately repair mixing equipment, scales, and ingredient/feed movement equipment in the mill for any inaccuracies or leaks.

(3) Evaluate grain and storage bins for leaks that will allow water to enter and cause spoilage.

(4) Use any broken bags quickly to minimize losses and the potential of misuse.

(5) Properly dry ingredients to the appropriate moisture level to eliminate mold growth and contamination.

(6) Establish an effective rodent and insect control program to reduce damage and losses from rats, mice, birds, varmints, and insects.

(7) Routinely examine feed conveyers, feed auger lines, and feed delivery trucks for leaks.

Optimal Feeder Design

When one considers the amount of feed that will go through a feeder during its lifetime, it only stands to reason that careful consideration should be given to the selection of the feeder. If one assumes that a feeder will provide the feed for 25 pigs each day, that each pig will consume 4.5 lb of feed each day, and that the feeder will have a lifetime of 10 years, approximately 205 tons of feed will be delivered by the feeder during its lifetime (25 pigs × 4.5 lb feed/day × 365 days/year × 10 years). This fact, coupled with the reality that pigs tend to be messy eaters, highlight the importance of using a properly designed feeder to keep unnecessary feed waste to a minimum.

The optimal feeder design should allow pigs to eat in a natural upright position while standing at the feeder. Improperly designed feeders make it necessary for pigs to back away from the feeder to chew and swallow after a bite of feed has been secured. The lips on feeders should be of a height that restricts spillage but not higher than 8 inches. Feeder lip heights greater than 8 inches will result in pigs having to step into the feeder to get feed, and will cause greater feed waste. Also, since eating a dry feed necessitates drinking water, feeders that incorporate the water supply into the feeder helps to reduce the need for pigs to walk away from the feeder (often with a mouthful of feed) to get water.

Feeder Adjustment

One of the most important, yet most underutilized, management practices for minimizing feed wastage is proper feeder adjustment. Too often feeders are never adjusted, or they are only adjusted when a new group of pigs enter a pen. Checking and adjusting feeders should be a normal part of the daily routine. Feeder openings that are set too wide can result in feed wastage from feed sorting and stale feed. Feeder openings that are closed down too tightly can reduce feed intake and growth, and may increase the incidence of fighting among pigs. Smith et al. (2003) reported that weanling pig performance was maximized when the feeder opening was adjusted so that the feeder gap allowed for 40% of the trough to be covered with feed. These authors also found that properly adjusted feeders reduced the time spent eating (because pigs were able to more quickly eat to satisfaction) and, therefore, increased the number of pigs that could be fed per feeder space. Based on these and similar results, it is generally recommended that feeders be adjusted down until slightly less than half of the feeder trough has feed exposed.

Conclusions

Escalating feed and fuel prices have led to significantly higher costs of production for pork producers. While there is likely not a single practice or strategy that will completely offset these higher input costs, there are several options available to producers to help lessen their effects on profitability. However, each strategy should be carefully evaluated within their production system to ensure animal performance and cost of gain is not negatively affected.

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Table 1. Feed Intake and Other Performance Traits in a Sample of Pig Genotypes[a]

Genotype	Sex	Feed Intake (lb/d)	Daily gain (lb/d)	Feed/gain	Lean gain (g/d)
1	Barrow	5.47	2.25	2.43	342
2	Barrow	6.06	2.07	2.93	267
3	Barrow	5.80	2.31	2.50	311
4	Barrow	5.80	2.12	2.74	272
5	Gilt	5.16	1.98	2.60	324
6	Barrow	4.89	2.03	2.41	316
7	Gilt	4.59	1.87	2.45	319
8	Barrow	5.73	2.12	2.71	253
9	Gilt	5.56	2.03	2.74	287

[a]Adapted from Schinckel (1994). Over the growing-finishing period (55 to 258 lb), pigs were fed four diets containing 1.30%, 1.15%, 1.05%, and 0.95% lysine.

Table 2. Feed Intake and Growth Performance of Pigs Raised in Different Health Status Environments[a]

	Growing Environment[b]		
	SPF	Conventional	SEW
Initial BW, lb	59.1	68.8	63.9
Final BW, lb	238.3	239.2	237.4
Feed intake[c], lb/d	4.94	4.89	4.23
Gain[c], lb/d	2.03	1.92	1.59
Feed/gain[c]	2.42	2.55	2.67
Lean gain, lb/d	0.95	0.93	0.77

[a]Adapted from De Lange and Baidoo (2007).
[b]SPF (specific pathogen free), high health status; Conventional, conventional health status; SEW (segregated early weaning), low health status where pigs from six different farms were comingled at weaning in a common nursery.
[c]Statistically corrected for differences in initial body weight between the three groups.

Table 3. The Effect of the Number of Diets used in a Phase Feeding Program on Total Feed Costs Per Pig[a]

Number of Diet Phases	Diet Cost Per Pig[b]	Savings Over 2 Diet Phase Feeding	Incremental Savings Per Additional Diet
2	$85.98		
3	$84.87	$1.11	$1.11
4	$84.48	$1.50	$0.39
5	$84.15	$1.83	$0.33
6	$83.92	$2.06	$0.23
9	$83.80	$2.18	$0.12
12	$83.75	$2.23	$0.05

[a]Pig growth performance (45 to 265 lb) is assumed to be equal in all phases.
[b]These examples assume a corn cost of $6 per bushel and a soybean meal (48%) cost of $350 per ton.

Table 4. Performance of Barrows and Gilts Fed a Similar Diet[a]

	Sex		
	Barrows	Gilts	Difference[b]
Initial weight, lb	52.7	53.8	
Final weight, lb	231.7	229.5	
Feed intake, lb/d	5.34	4.76	+11%
Gain, lb/d	1.85	1.72	+8%
Feed/gain	2.87	2.78	+3%
Dressing percentage, %	80.9	80.3	+0.7%
Carcass lean yield, %	48.1	50.5	–5%

[a]Adapted from Patience et al. (1995).
[b]Calculated as follows: [performance of barrows – performance of gilts] ÷ average performance of the two sexes.

Table 5. Impact of Vitamin and Trace Mineral Premix Withdrawal for 28 Days Preslaughter on Growth Performance and Carcass Characteristics[ab]

	Corn-Soybean Meal Diet with Full Supplementation[c]	Corn- Soybean Meal Diet with Supplement Withdrawal[c]
Daily gain, lb	2.23	2.30
Daily feed, lb	7.76	7.90
Feed/gain	3.48	3.43
Dressing percentage, %	73.89	73.40
Loin eye area, in^2	5.94	6.05
Backfat depth, in	0.83	0.79

[a]Adapted from Shaw et al. (2002).
[b]Prior to the dietary treatments evaluated during the 28 days preslaughter all pigs received diets that were balanced for all nutrients.
[c]The corn-soybean meal diet with full supplement contained the vitamin and trace mineral premixes and the full amount of dietary inorganic phosphate. The corn-soybean meal diet with supplement withdrawal had the vitamin and trace mineral premixes and two-thirds of the dietary inorganic phosphate removed.

Table 6. Impact of Pelleting Corn-Based Diets on Finishing Pig Performance and Nutrient Digestibility[a]

	Meal	Pellet	Difference, %
Pig Performance			
Initial weight, lb	150		
Final weight, lb	263		
Average daily gain, lb	1.83	1.99	+8.7
Average daily feed, lb	6.65	6.86	+3.2
Feed/gain	3.65	3.46	+5.2
Apparent Nutrient Digestibility, %			
Dry matter	86.2	86.9	+0.8
Nitrogen	83.1	83.4	+0.4
Gross Energy	87.0	87.3	+0.3

[a]Adapted from Wondra et al., 1992.

Table 7. Effect of Pelleting Diets Based on Canola and Barley or Barley-Wheat on Finishing Pig Performance[a]

	Meal	Pellet	Difference, %
Pig Performance			
Initial weight, lb	130		
Final weight, lb	220		
Average daily gain, lb	1.61	1.92	+19.2
Average daily feed, lb	6.02	6.56	+9.2
Feed/gain	3.78	3.43	+9.3

[a]Adapted from Swine Nutrition Guide, Prairie Swine Centre, p. 222 (1995).

Table 9. Optimal Market Weight of PIC327 Barrows and Gilts at Two Different Packers[a]

	Feed Price, $/lb			
	$0.06	$0.08	$0.10	$0.12
Optimal Weight for Pigs Marketed at Hormel[b]				
Barrows, lb	286	282	278	275
Gilts, lb	285	282	280	278
Optimal Weight for Pigs Marketed at Tyson[b]				
Barrows, lb	290	287	285	282
Gilts, lb	290	288	286	284

[a]Williams et al., 2008 (unpublished data from PIC).
[b]Optimal market weight shown is the weight at which profit margin was maximized.

Table 10. The Effect of Feed Wastage on Feed Cost Per Pig.

Feed Waste, %	Feed for 200 lb of Pig Gain[1]	Feed Cost Per Pig[2]	Feed Waste Cost Per Pig
0	550	$66.00	----
2	561	$67.32	$1.32
4	572	$68.64	$2.64
6	583	$69.96	$3.96
8	594	$71.28	$5.28
10	605	$72.60	$6.60
12	638	$76.56	$10.56
14	660	$79.20	$13.20

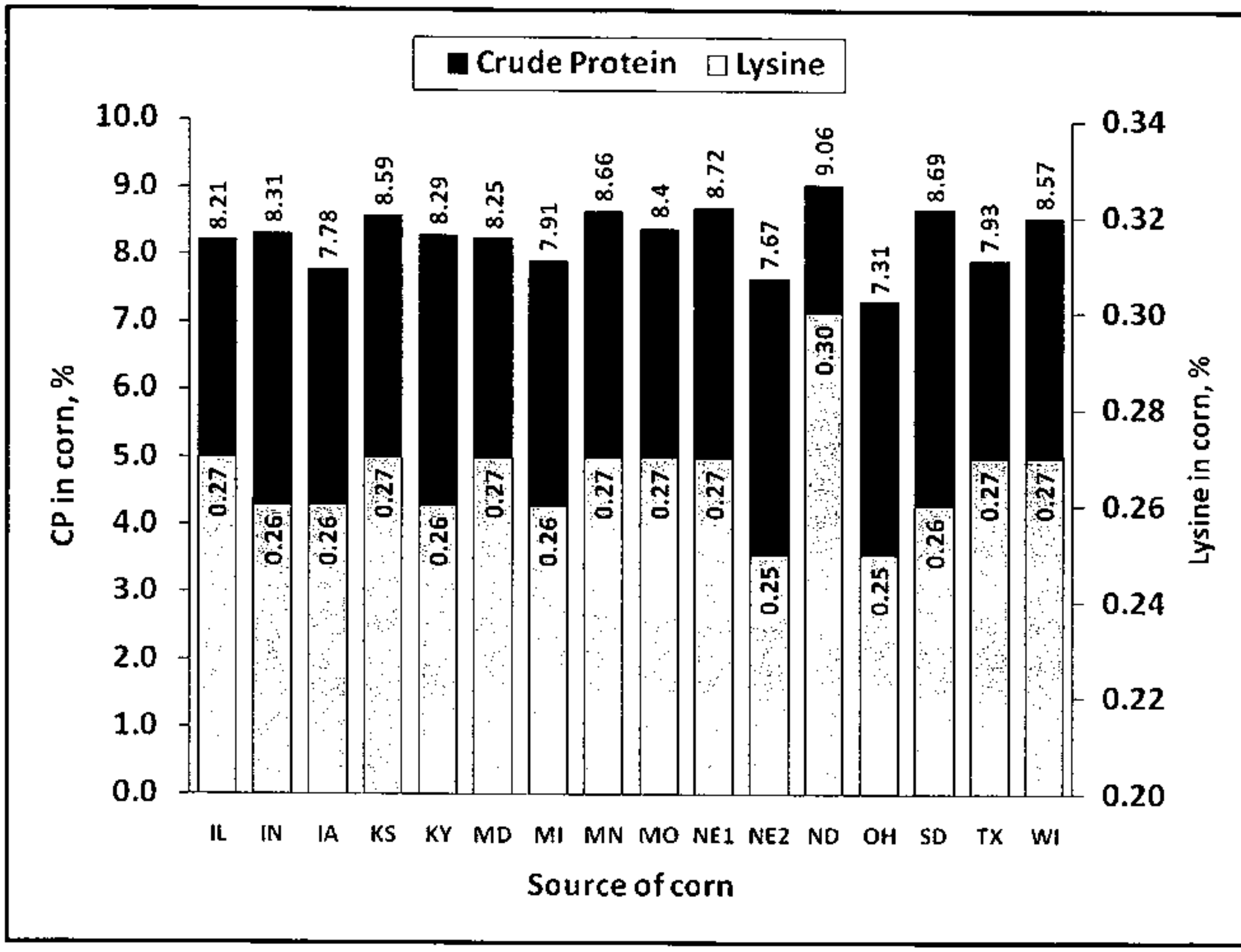
[a]Assumes a feed conversion (feed/gain) of 2.75 from 50 to 250 lb.
[b]Assumes an average feed cost of $0.12/lb.

Table 8. Expected Return from Selling Pigs at a Heavier Weight Based on Different Feed Prices[a]

	Feed Cost, $/lb				Feed Cost, $/lb			
	$0.10	**$0.11**	**$0.12**	**$0.13**	**$0.10**	**$0.11**	**$0.12**	**$0.13**
Current weight of pig, lb	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
Number of extra days to feed	7	7	7	7	7	7	7	7
Expected daily gain, lb	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
Expected added gain, lb	15.4	15.4	15.4	15.4	15.4	15.4	15.4	15.4
Expected market weight, lb	255.4	255.4	255.4	255.4	255.4	255.4	255.4	255.4
Expected feed efficiency, feed/gain	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Expected additional feed, lb	61.6	61.6	61.6	61.6	61.6	61.6	61.6	61.6
Expected yield, %	75	75	75	75	75	75	75	75
Base live market price, $/cwt	$51	$51	$51	$51	$51	$51	$51	$51
Percentage of downers/mortalities	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Opportunity cost of space[b], $	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21	$0.21
Added feed cost per head, $	$6.16	$6.78	$7.39	$8.01	$6.16	$6.78	$7.39	$8.01
Cost of downers/mortalities, $	$0.24	$0.24	$0.24	$0.24	$0.24	$0.24	$0.24	$0.24
Total cost of added weight, $	$6.61	$7.23	$7.85	$8.46	$6.61	$7.23	$7.85	$8.46
Change in packer premium[c], $/head	$0.00	$0.00	$0.00	$0.00	– $0.50	– $0.50	– $0.50	– $0.50
Expected change in return from selling at a later date, $/head	$1.24	$0.62	$0.01	– $0.61	$0.74	$0.12	– $0.49	– $1.11

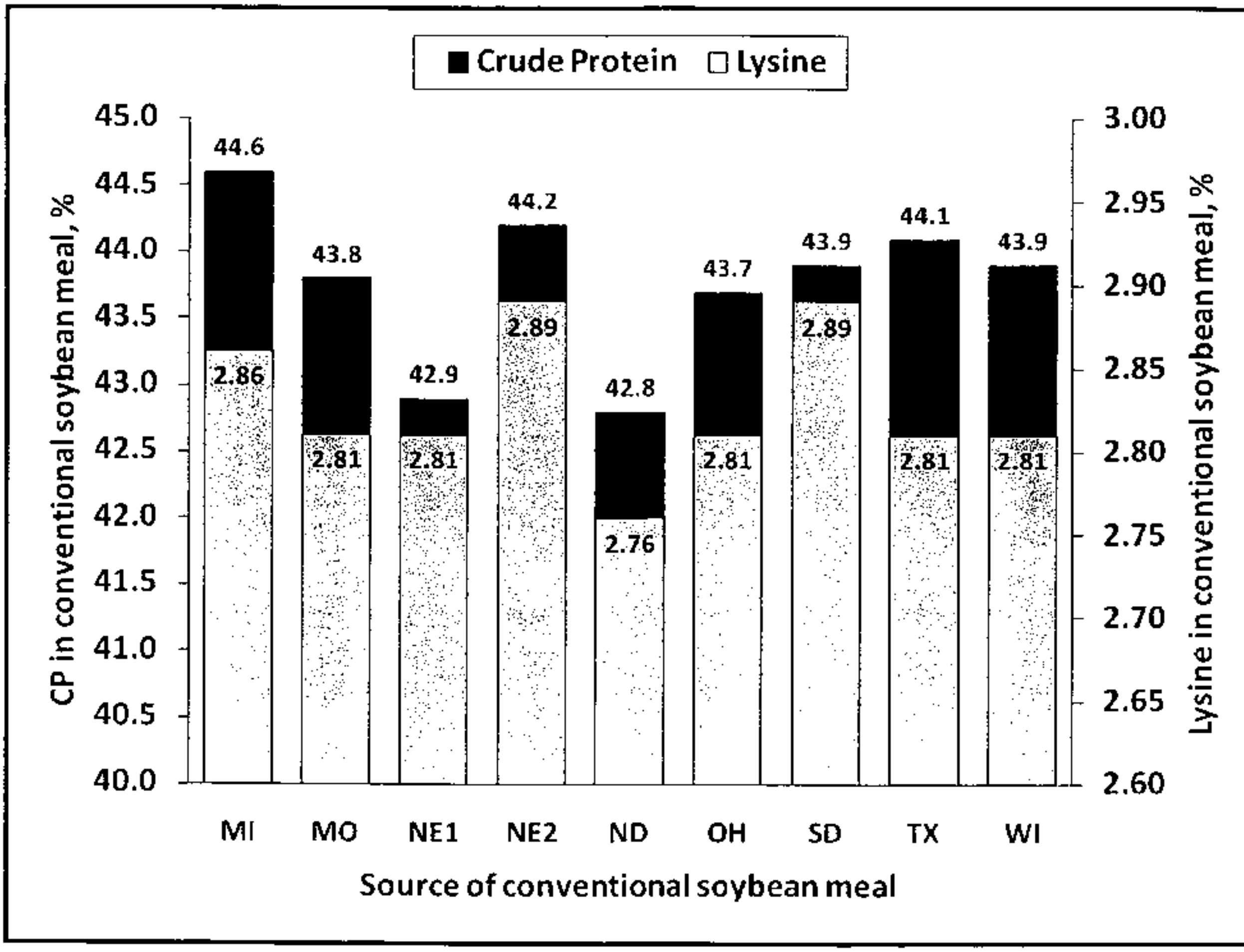
[a]Based on Swine Marketing Decision Calculator (Lawrence, 2008).
[b]Cost of keeping animals in the facility for an additional 7 days, excluding fixed costs.
[c]Change in packer premium could result from sort loss and (or) lean discount.

Figure 1. Variability in the Crude Protein and Lysine Content of Different Sources of Corn[a]



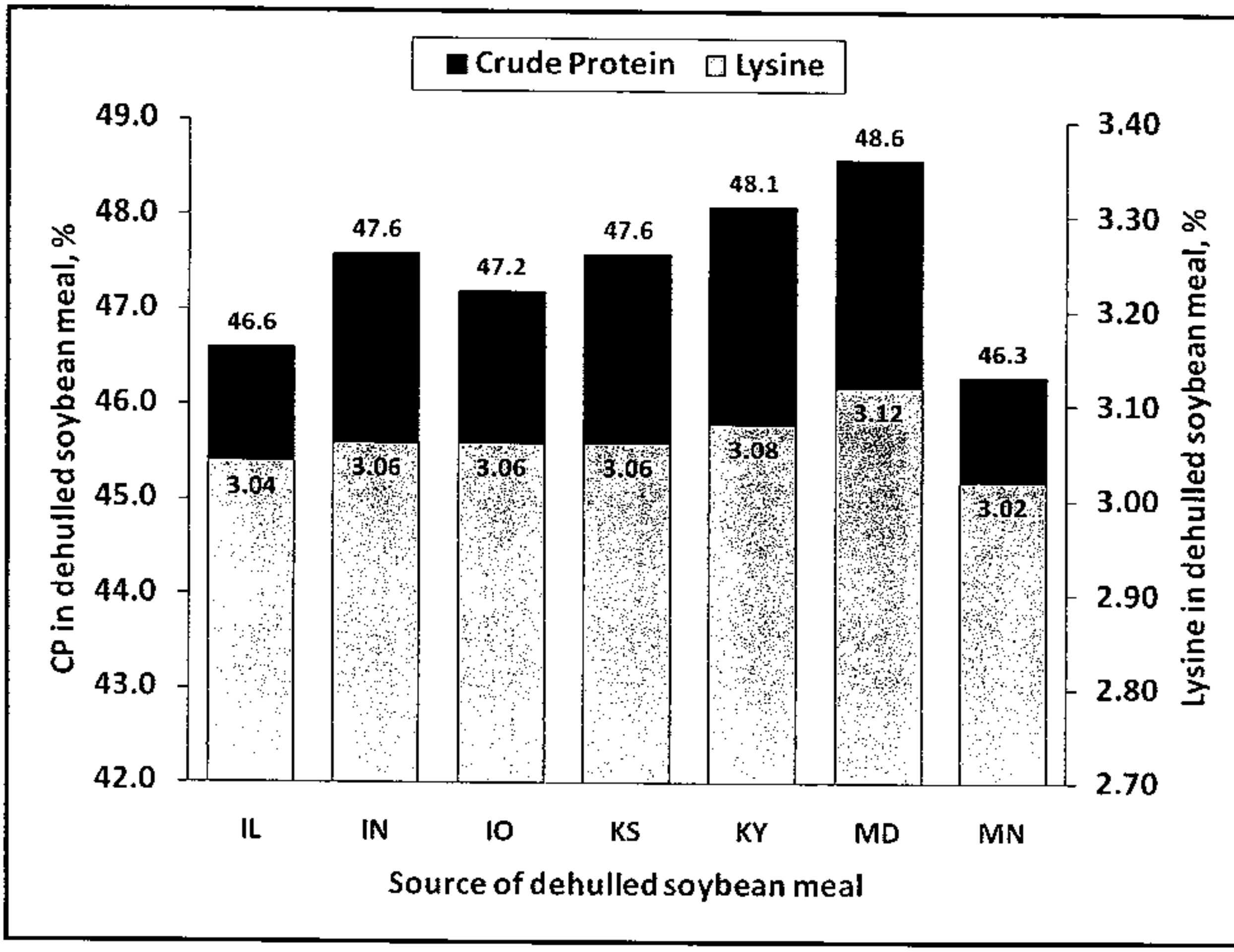
[a]Taken from Cromwell et al. (1999).

Figure 2. Variability in the Crude Protein and Lysine Content of Different Sources of Conventional Solvent-Extracted Soybean Meal with Hulls[a]



[a]Taken from Cromwell et al. (1999).

Figure 3. Variability in the Crude Protein and Lysine Content of Different Sources of Solvent-Extracted Dehulled Soybean Meal[a]



[a]Taken from Cromwell et al. (1999).

NRCS Nutrition and Management Standards That Could Affect How We Feed Pigs

Alan Sutton[1], Brian Richert[1], Joe Harrison[2], Rebecca White[2] Galen Erickson[3], Robert Burns[4], Todd Applegate[1] and Glenn Carpenter[5]

SUMMARY

Concentrated animal feeding operations (CAFO) and many mid-sized animal feeding operations (AFO) are required to comply with state and federal environmental regulations related to the protection of water quality. In the future, EPA and potentially state regulatory agencies will implement air quality standards involving CAFOs and AFOs. Most current regulations are based on the need to account for and control nutrient flow on-farm to minimize buildup, leaching and runoff of nutrients that may pose a risk to surface and ground water quality. Attempts to control nutrient flow include the requirements for nutrient management plans, conservation practice plans, storm water pollution prevention plans, chemical and fuel handling, animal mortality management, and emergency action plans. The overall goal of the nutrient management plan on a swine farm is to obtain a whole farm nutrient mass balance while producing pork products efficiently and profitably. Feed management is a critical aspect of nutrient management plans since on most swine farms the greatest import of nutrients on the farm is from feeds. A National Resource Conservation Service (NRCS) Feed Management Standard (592) was developed to encourage and assist livestock and poultry producers to use practices that will maintain animal productivity, while minimizing nutrient excretion and to potentially improve net farm income by using feed nutrients more efficiently. The consulting nutritionist is a key in helping pork producers develop a feed management plan tailored for a specific pork operation after critical assessments of feed formulations and management practices are conducted to see if any additional efficiencies in nutrient flow on the farm can be obtained. Through the Environmental Quality Incentives Program (EQIP) swine producers can obtain cost-share funds to offset additional costs for the development of a feed management plan which will result in improving their environmental sustainability. Through the development of feed management plans, swine producers may realize a reduction in import of feed nutrients, a more balanced on-farm nutrient plan, and potentially a more sustainable business.

INTRODUCTION

The goal of swine operations is to economically and profitably produce wholesome, nutritious, protein products for human consumption. However, this must be accomplished in a manner that is environmentally sustainable and socially acceptable. With today's high feed prices, meeting all of these requirements is very challenging. Concentrated animal feeding operations (CAFO) and many mid-sized animal feeding operations (AFO) are required to comply with state and federal environmental regulations specifically related to the protection of water quality and potentially in the future to meet air quality standards. Excess accumulation and poor management of nutrients on farms have been the concern of regulatory agencies since these conditions can lead to contamination of water sources. This paper will discuss the impact of feed and feed management practices on whole farm nutrient balance, the NRCS

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Feed Management Standard (592), and the role of the nutritionist on assisting pork producers to enhance nutrient efficiency and minimize nutrient excretions as a part of a nutrient management plan for the operation.

WHOLE FARM NUTRIENT BALANCE

To meet recent National regulatory requirements of EPA for water quality, CAFOs must develop a nutrient management plan for their operation (USEPA, 2001). This is focused on a concept of achieving a whole farm nutrient balance for the operation. Koelsch and Lesoing (1999) illustrated (Figure 1) the whole farm nutrient balance concept and identified typical nutrient inputs (imports) on the farm through the purchase of feed and fertilizer, recycling of irrigation water (in some areas of the US), introduction of animals and carryover of nitrogen in the soil from production of legume crops. Managed output of nutrients from the operation included the sale of animal products (meat), crops not fed to the animal enterprise and potentially export manure off-farm (especially when there is a significant accumulation of nutrients on the farm location). Nutrient balance or imbalance is determined by the difference in nutrient inputs minus managed nutrient outputs. Gaseous emissions of some nutrients (nitrogen (N), sulfur and other volatile compounds) is part of the nutrient balance scheme, however, currently it is very hard to document these gaseous losses. The intent of evaluating the relative levels of nutrient inputs and outputs is to determine the nutrient flow, the relative impacts of these sources and whether there is a major imbalance, and to assess where changes can be made to reduce significant imbalances.

Using a similar concept, the Natural Resource Conservation Service (NRCS) (NRCS, 1999; 2001) developed the Comprehensive Nutrient Management Plan (CNMP) as a part of a new Nutrient Management Conservation Practice Standard (590) with the purpose

"To budget and supply nutrients for plant production.

To properly utilize commercial fertilizers, animal manures, and other materials as plant nutrient resources and soil amendments.

To minimize agricultural pollution of surface and ground water resources.

To maintain or improve the physical, chemical and biological condition of soil." (NRCS, 2001).

Consequently, a CNMP has 6 components including the assessment and development of plans for feed management, manure and wastewater handling and storage, nutrient management, land treatment practices, record keeping and if applicable, alternative uses of manure (treatment alternatives). Development of a feed management plan in a CNMP with the 592 standard is still optional, but highly recommended.

FEED MANAGEMENT PRACTICES

Feed represents the largest import of nutrients to the farm (Klopfenstein, et al, 2002) therefore, there may be feed management opportunities currently existing to reduce imports of nutrients to swine operations. Since consulting nutritionists play such a key role with regard to importation of nutrients to the farm, a systematic approach to evaluate the role that feed management has on whole farm nutrient balance is warranted.

NRCS (2003) implemented a Feed Management Conservation Practice Standard (592) (See Appendix 1) that was defined as "managing the quantity of available nutrients fed to livestock and poultry for their intended purpose with the purposes of the 592 to

"Supply the quantity of available nutrients required by livestock and poultry for maintenance, production, performance, and reproduction; while reducing the quantity of nutrients, especially N and phosphorus (P), excreted in manure by minimizing the over-feeding of these and other nutrients.

Improve net farm income by feeding nutrients more efficiently." (NRCS, 2003)

The ultimate goal of using the 592 standard is to develop a farm specific Feed Management Plan (FMP). A five step process has been adopted for the development and implementation of a FMP (Figures 2 and 3). By implementing a FMP as outlined in the 592 standard, potential environmental benefits are:

Reduction of on-farm import of nutrients

Reduction of nutrients in manure for subsequent land application and potential losses to ground and surface water, and

Reduction of nutrients in manure and subsequent volatile losses.

The conditions where the practice applies includes: 1) whole farm nutrient imbalance with more nutrients imported on the farm than are exported and/ or utilized by cropping programs; 2) soil nutrient build-up on the operation due to land application of manure; 3) land base not large enough to allow nutrients to be applied at rates recommended by soil test and utilized by crops in a rotation; and 4) livestock and poultry operations seeking to enhance nutrient efficiencies.

Adjustments to nutrient levels shall be provided to meet specific genetic potential, environmental demands, and/or requirements to insure health, well-being and productivity.

Examples of some feed management practices and/or diet manipulation technologies can be used to reduce N, P and other excreted nutrients while maintaining the health, well-being and productivity of pigs are:

- Reducing feed wastage.
- Formulating diets closer to animal requirements.
- Reducing protein and supplementing with synthetic amino acids.
- Using highly digestible feeds, as appropriate, in the diet.
- Using phytase and reducing the supplemental P content of the diet.
- Using selected enzymes or other products to enhance feed digestibility or feed use efficiency.
- Using feed processing techniques to increase nutrient digestibility.
- Using growth promotants as allowed by law.
- Monitoring mineral content of water.
- Implementing phase feeding.
- Implementing split-sex feeding.
- Using other feed management or diet manipulation technologies that have demonstrated the ability to reduce manure nutrient content.

A national feed management education project is being conducted to develop and integrate a national feed management education program and assessment tools to be used in a CNMP (Harrison, et al, 2007). Project outcomes include: a systematic approach to assess feed management on a livestock or poultry operation, development of a training curriculum and educational resources, and implementation tools (see fact sheets that support adoption of NRCS Feed Management Standard 592 at http://www.puyallup.wsu.edu/dairy/nutrient-management/publications.asp).

In the context of the NRCS 592 standard, a technical service provider (TSP), NRCS personnel or CNMP planner determines if an operation needs to investigate the feed management aspects of the operation, its impact on nutrient balance and whether it is a candidate for a feed management plan (FMP) (Figure 4). If this looks beneficial, a nutrition consultant can conduct an on-farm assessment to provide the basis for a FMP. The process for fulfilling the NRCS 592 standard is to develop the FMP, implement the FMP, monitor the FMP with record keeping, and routine manure and feed sampling and analyses.

A training curriculum will be used in workshops and available on-line, with the outcome that TSP, NRCS personnel or CNMP planners will be given continuing education units towards a feed management component certification for CNMP development. Another training curriculum will be developed for workshops and on-line for nutrition consultants towards an ARPAS certification in Feed Management. An exam is available and implemented by ARPAS for the certification. Additional educational resources for feed management assessment include fact sheets, 1) an opportunity checklist for beef, dairy, poultry and swine that can be used by TSP to assess the opportunity/need to develop a FMP to improve nutrient balance on a farm, and 2) a feed management plan checklist for beef, dairy, poultry and swine that can be used by nutrition consultants to assess the impact and what measures can be taken in a FMP to improve nutrient balance on a farm (Harrison, et al, 2007) (See Appendix 2).

FEED MANAGEMENT PLANS AND SPECIFICATIONS

The following components shall be included in the feed management plan:

The type of technology, or technologies, and/or feeding practices that will be used on the operation.

Feed analyses and ration formulation information prior to and after implementation of feed management on the operation.

The estimated or measured nutrient content and volume of the manure prior to the implementation of feed management on the operation.

The estimated impact that feed management will have on manure nutrient content and volume.

Guidance for how often the feed management plan shall be reviewed and potentially revised.

The quantities and sources of N and P that will be fed.

Identification of the qualified feed management specialist who developed the plan. A nutritionist must be certified for development of feed management plans in CNMP if EQIP funds are used. This certification can be accomplished through passing an ARPAS test in Feed Management or through a similar certification process available provided by the state.

Feed management Plan OPERATION AND MAINTENANCE

The producer/client is responsible for the operation and maintenance of the feed management plan. Operation and maintenance activities address the following:

Periodic plan review to determine if adjustments or modifications are needed.

Routine feed analysis to document the rates at which N and P were actually fed. When actual rates fed differ from or exceed the planned rates, records will indicate the reasons for the differences.

Maintaining records to document plan implementation. As applicable, records include:

Records of feed analysis and ration formulation, including the record of ration formulation used prior to implementing the feeding strategy.

Records of the initial estimate of impact on the feeding strategy on manure nutrient content and volume.

Records of manure analyses and volumes before and after the feeding strategy was implemented to determine manure nutrient content and volume changes.

Dates of review and person performing the review, and any recommendations that resulted from the review.

Records of plan implementation shall be maintained for five years, or for a period longer than five years if required by other Federal, state, or local ordinances, program, or contract requirements.

IMPLICATIONS

Since environmental regulations will become more stringent in the future for CAFO and many mid-sized AFO, the requirement to document and control nutrient flow on livestock and poultry operations will be imperative in the near future. This will probably take the form of requiring extensive nutrient management plans or comprehensive nutrient management plans. Nutritionists have a key role in determining the import and management of feed nutrients in swine production operations. Assessment of feed formulations, feed processing, and use of feeding practices will be critical in reducing excess excretion of nutrients when there is a significant nutrient imbalance on the farm. After a thorough assessment, nutritionists are encouraged to develop feed management plans if it appears that the plan will help resolve whole farm nutrient imbalances. In addition, nutritionists can help other professional resource specialists in the development of an efficient, functional, and realistic comprehensive nutrient management plan for swine production operations. This is an opportunity for nutritionists to assist swine producers to remain economically viable and environmentally responsible.

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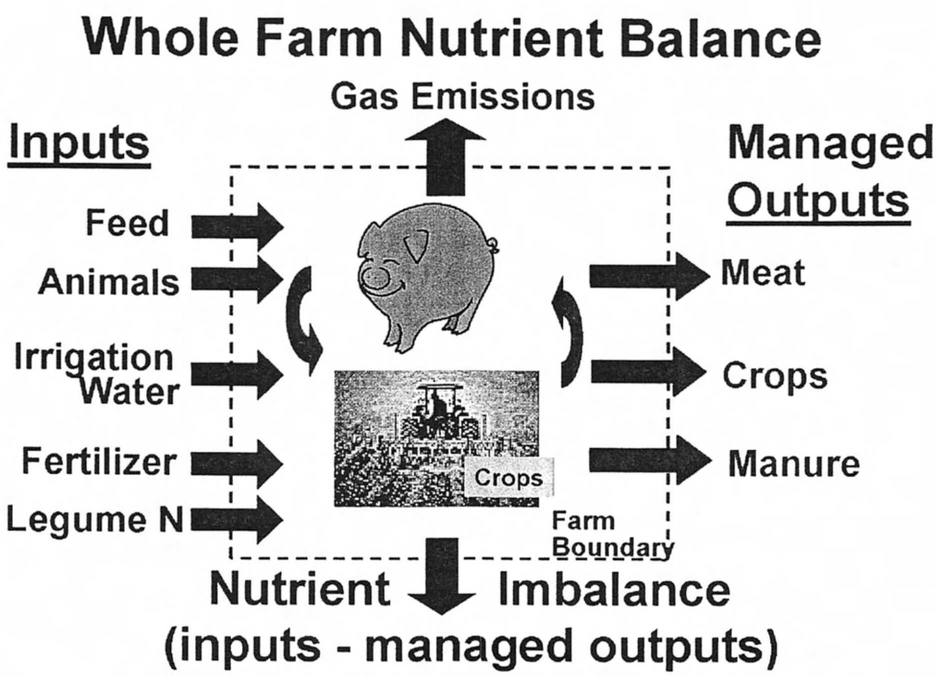
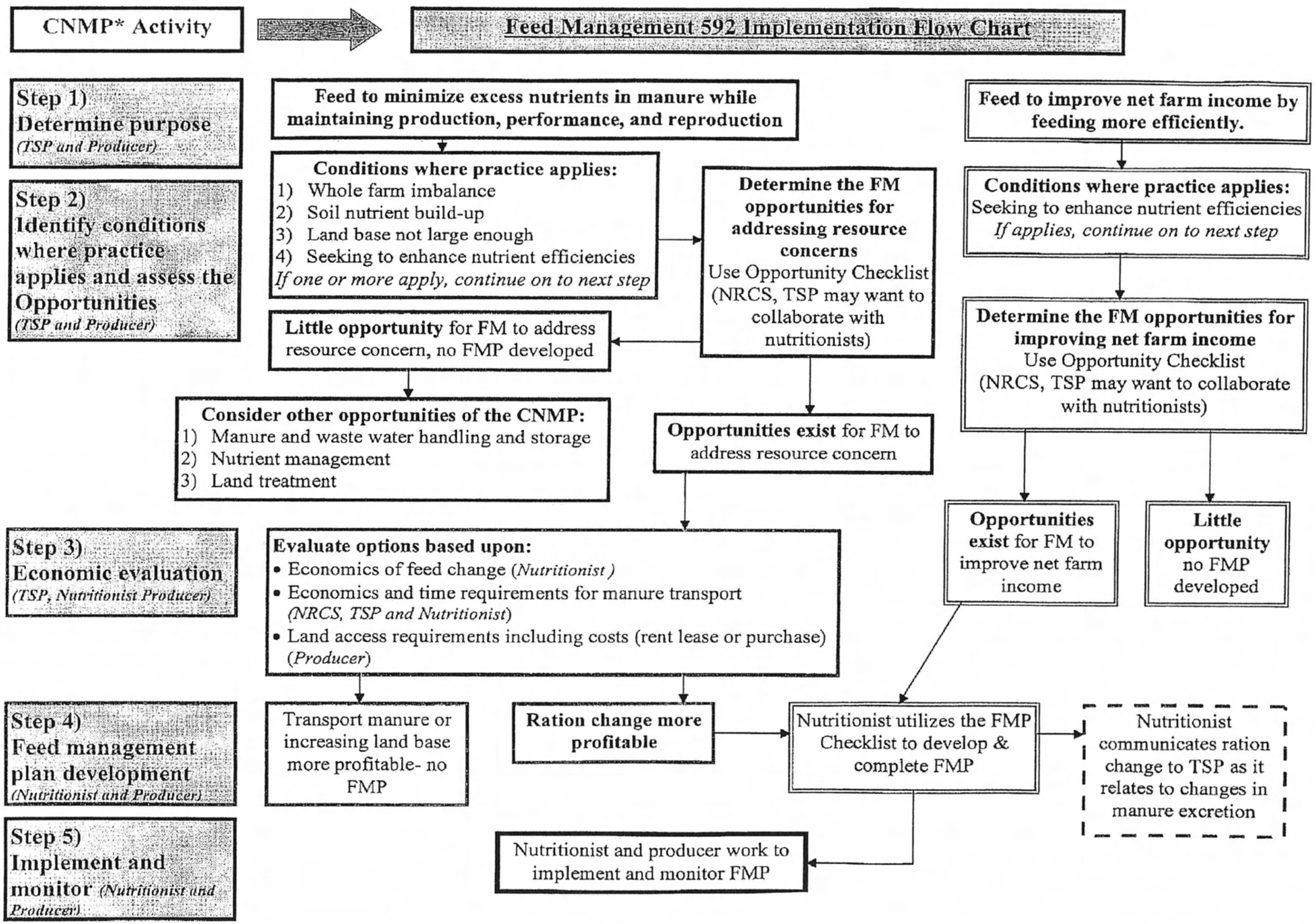


Figure 1.Whole farm nutrient balance of swine production operation illustrated by the balance of nutrient inputs with managed nutrient outputs. Gaseous losses and nutrient recycling are considered. (Adapted from Koelsch and Lesoing, 1999)


CNMP* Activity
Feed Management 592 Implementation Flow Chart
Step 1) Determine purpose (TSP and Producer)
Feed to minimize excess nutrients in manure while maintaining production, performance, and reproduction
Feed to improve net farm income by feeding more efficiently.
Step 2) Identify conditions where practice applies and assess the Opportunities (TSP and Producer)
Conditions where practice applies:
1) Whole farm imbalance
2) Soil nutrient build-up
3) Land base not large enough
4) Seeking to enhance nutrient efficiencies
If one or more apply, continue on to next step
Determine the FM opportunities for addressing resource concerns
Use Opportunity Checklist (NRCS, TSP may want to collaborate with nutritionists)
Conditions where practice applies:
Seeking to enhance nutrient efficiencies
If applies, continue on to next step
Little opportunity for FM to address resource concern, no FMP developed
Determine the FM opportunities for improving net farm income
Use Opportunity Checklist (NRCS, TSP may want to collaborate with nutritionists)
Consider other opportunities of the CNMP:
1) Manure and waste water handling and storage
2) Nutrient management
3) Land treatment
Opportunities exist for FM to address resource concern
Opportunities exist for FM to improve net farm income
Little opportunity no FMP developed
Step 3) Economic evaluation (TSP, Nutritionist Producer)
Evaluate options based upon:
• Economics of feed change (Nutritionist)
• Economics and time requirements for manure transport (NRCS, TSP and Nutritionist)
• Land access requirements including costs (rent lease or purchase) (Producer)
Step 4) Feed management plan development (Nutritionist and Producer)
Transport manure or increasing land base more profitable- no FMP
Ration change more profitable
Nutritionist utilizes the FMP Checklist to develop & complete FMP
Nutritionist communicates ration change to TSP as it relates to changes in manure excretion
Step 5) Implement and monitor (Nutritionist and Producer)
Nutritionist and producer work to implement and monitor FMP

Activity	Who is Involved with Activity
Step 1) Determine the Purpose Specific to the Farm	Step 1) Nutrient Management Planner and Producer
Step 2) Identify where Practice Applies and Assess the Opportunity for Adoption of 592 Standard	Step 2) Nutrient Management Planner and Producer
Step 3) Evaluate the Economics of Making a Ration Change vs Transporting Manure	Step 3) Nutrient Management Planner, Producer, and **Nutritionist**
Step 4) Feed Management Plan Development	Step 4) Producer and **Nutritionist**
Step 5) Feed Management Plan Implementation and Monitoring	Step 5) Producer and **Nutritionist**

Figure 3. Feed Management Development and Implementation Flow Chart for Adoption of USDA-NRCS* Feed Management 592 Practice Standard.

*USDA-NRCS – United States Department of Agriculture – Natural Resources Conservation Service

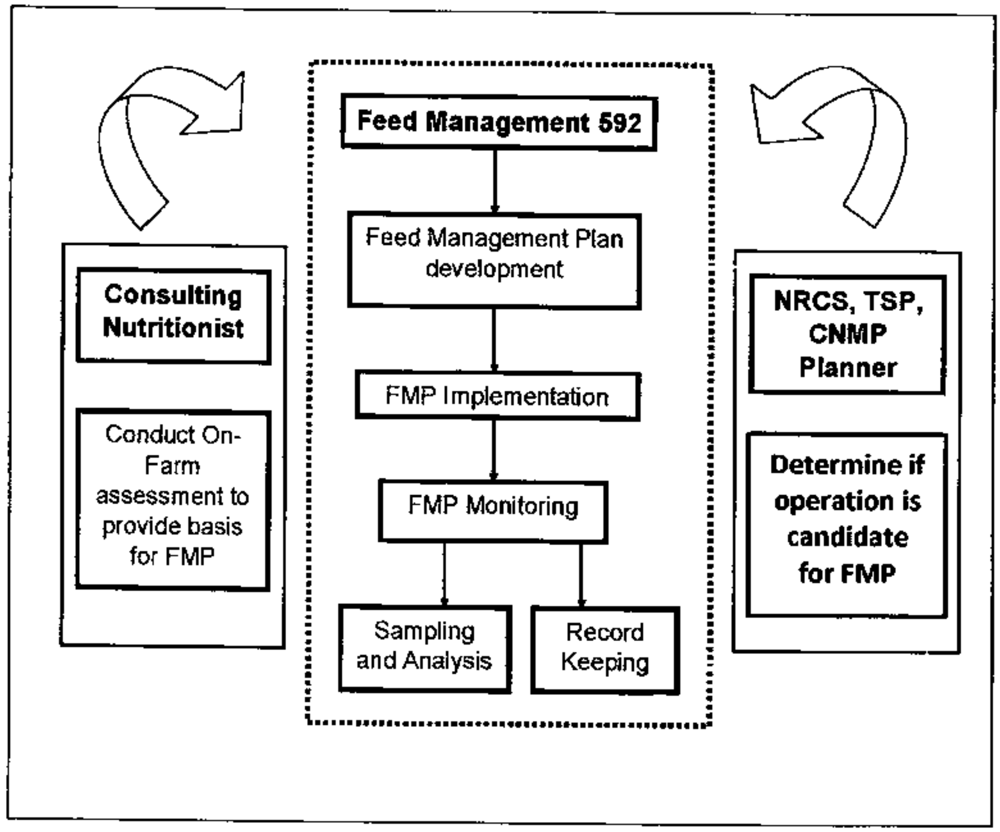


Figure 4. Role of a technical service provider and a consulting nutritionist in the development, implementation and monitoring of a feed management plan for an animal production operation. (Harrison, et al, 2007).

(APPENDIX 1)

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

FEED MANAGEMENT

(No. of Systems and AUs Affected)

CODE 592

DEFINITION

Managing the quantity of available nutrients fed to livestock and poultry for their intended purpose.

PURPOSE

- Supply the quantity of available nutrients required by livestock and poultry for maintenance, production, performance, and reproduction; while reducing the quantity of nutrients, especially nitrogen and phosphorus, excreted in manure by minimizing the over-feeding of these and other nutrients.
- Improve net farm income by feeding nutrients more efficiently.

CONDITIONS WHERE PRACTICE APPLIES

Confined livestock and poultry operations with a whole farm nutrient imbalance, with more nutrients imported to the farm than are exported and/or utilized by cropping programs.

Confined livestock and poultry operations that have a significant build up of nutrients in the soil due to land application of manure.

Confined livestock and poultry operations that land apply manure and do not have a land base large enough to allow nutrients to be applied at rates recommended by soil test and utilized by crops in the rotation.

Livestock and poultry operations seeking to enhance nutrient efficiencies.

CRITERIA

General Criteria Applicable to All Purposes

The diets for specific species of animals shall be developed in accordance recommendations from one of the following:

- Standards outlined in the most current recommendations of the National Research Council (NRC).
- Recommendations of the land grant university.
- Standards developed by the professional nutritionists of livestock and poultry production companies, feed companies, and/or feed suppliers.

Laboratory analysis shall be done on the formulated diet, or on the feed ingredients used to formulate the diet, to determine its nutrient content.

Feed analyses shall be conducted by laboratories whose tests are accepted by the Land Grant University in the state in which the feeding strategy will be implemented. Data from analyzed feed ingredients and/or appropriate historic feed analysis information for the operation will be used for adjustments of ration formulation.

Diets and feed management strategies shall be developed by professional animal scientists, independent professional nutritionists or other comparably qualified individuals. When required by state policy or regulation, animal nutritionists shall be certified through any certification program recognized within the state.

Diets shall be formulated to provide the quantities and correct relative ratios of available nutrients required by the animal species to meet species to meet the goals for which the plan is being developed.

Adjustments to nutrient levels shall be provided to meet specific genetic potential, environmental demands, and/or requirements to insure health, well-being and productivity.

One or more of the following feed management practices and/or diet manipulation technologies shall be used to reduce N, P and other excreted nutrients while maintaining the health, well-being and productivity of the animal.

- Formulating diets closer to animal requirements.
- Reducing protein and supplementing with amino acids (non-ruminants).
- Manipulating the crude protein and energy (carbohydrate and fat) content of the diet to enhance the availability of amino acids (ruminants).
- Using highly digestible feeds, as appropriate, in the diet.
- Using phytase and reducing the supplemental phosphorus content of the diet (non-ruminants)
- Reducing the phosphorus content of the diet of ruminants when it is being overfed.
- Using selected enzymes or other products to enhance feed digestibility or feed use efficiency.
- Using growth promotants as allowed by law.
- Implementing phase feeding.
- Implementing split-sex feeding.
- Using other feed management or diet manipulation technologies that have demonstrated the ability to reduce manure nutrient content.

When analysis of manure is done to determine manure nutrient content, the analysis shall be performed by laboratories whose results are accepted by the Land Grant University in the state in which the feeding strategy was implemented.

CONSIDERATIONS

Consider nutrient requirements for production based upon stage of growth, intended purpose of the animal and the type of production (e.g., meat, milk, eggs) involved.

Use management practices described in the NRCS Nutrient Management (Feed Management) Technical Notes for the specific animal species.

Analyzing the drinking water consumed by the animals to determine its nutrient content, and adjusting the diet to account for this source of nutrients.

Different feed ingredients (e.g. by- products) and their potential impacts on the nutrient content of excreted manure.

The potential impact of feed management on the volume of manure excreted and on manure storage requirements.

The impact of feed management practices, animal management practices, and diet manipulation on manure odors, pathogens, animal health and well-being.

Using concentrates and forages grown on the farm to minimize the quantity of nutrients imported to the farm, and to maximize the recycling of nutrients on the farm.

Analyzing excreted manure or manure from storage facilities to determine manure nutrient content and to estimate the impact of the feeding strategy.

PLANS AND SPECIFICATIONS

Plans and specifications for feed management shall be in keeping with the requirements of this standard. They shall describe the specific feed management practices and/or technologies that are planned for the operation.

The following components shall be included in the feed management plan:

- The type of technology, or technologies, and/or feeding practices that will be used on the operation.
- Feed analyses and ration formulation information prior to and after implementation of feed management on the operation.

- The estimated, or measured, nutrient content of the manure prior to the implementation of feed management on the operation.
- The estimated impact that feed management will have on manure nutrient content.
- Guidance for how often the feed management plan shall be reviewed and potentially revised.
- The quantities and sources of nitrogen and phosphorus that will be fed.
- Identification of the qualified feed management specialist who developed the plan.

OPERATION AND MAINTENANCE

The producer/client is responsible for the operation and maintenance of the feed management plan. Operation and maintenance activities address the following:

- Periodic plan review to determine if adjustments or modifications are needed.
- Routine feed analysis to document the rates at which nitrogen and phosphorus were actually fed. When actual rates fed differ from or exceed the planned rates, records will indicate the reasons for the differences.
- Maintaining records to document plan implementation. As applicable, records include:
    - Records of feed analysis and ration formulation, including the record of ration formulation used prior to implementing the feeding strategy.
    - Records of the initial estimate of the impact the feeding strategy was expected to have on reducing manure nutrient content.
    - Records of any manure analysis that was done after the feeding strategy was implemented to determine manure nutrient content.
    - Dates of review and person performing the review, and any recommendations that resulted from the review.

Records of plan implementation shall be maintained for five years, or for a period longer than five years if required by other Federal, state, or local ordinances, program, or contract requirements.

(Appendix 2)

Feed Management

A Key Ingredient in Livestock

SWINE
Feed Management Plan Checklist

Feeding management is one of six components of a Comprehensive Nutrient Management Plan (CNMP) as defined by the Natural Resource Conservation Service. Feed management practices may reduce the volume and/or nutrient content of manure and may be an effective approach to minimizing the import of nutrients to the farm. Feeding management as part of a CNMP should be viewed as a "consideration" but not a "requirement" as some practices will not be economical on some pork operations. The following checklist is designed to assist pork producers and their nutritionist or nutrient management advisor to determine feeding management factors that affect nutrient management. The checklist is meant to be used as an *on-farm* assessment tool. The factors contained in this assessment can be used as a guide to document or identify feeding management practices that will contribute to achieving nutrient balance at a whole farm level. Nitrogen and phosphorus are the two nutrients that are required to be managed as part of a CNMP. When nitrogen and phosphorus imports exceed nitrogen and phosphorus exports there is an imbalance at a whole farm level. These imbalances may lead to impaired water quality in nearby water bodies due to surface runoff or leaching of nutrients to ground water. Excess nitrogen can also be volatilized and contribute to impaired air quality.

Pork Operation Name ____

Date Completed_____________________________________

Producer Signature__________________________________

Advisor Signature ___________________________________

On the following pages is a list of feeding management practices that can affect nutrient balance. Please read through each feeding management consideration and record your answer.

Feed Management Plan Checklist

Feed Management Considerations	Has it been implemented?	Was it considered?		Will it be economical?		Will it be implemented?		Will it be considered in the future?		Benefit to environment
		Yes	No	Yes	No	Yes	No	Yes	No	
Targeting Nutrient Requirements										
Formulate multiple rations to meet nutrient requirements of growing pigs and breeding herd (phase feeding)										N, NH3, P
Formulate and feed split-sex diets										N, NH3, P
Analyze CP and AA content of ingredients or rations routinely										N, NH3
Analyze total and available P content of ingredients or rations routinely										P
Analyze Ca content of ingredients or rations routinely										P
Diet reformulation with changes in ration feedstuffs										N, NH3, P
Ingredients screened for anti-nutritional factors (ANF's) and molds										N, NH3, P

Feed Management Considerations	Has it been implemented?	Was it considered?		Will it be economical?		Will it be implemented?		Will it be considered in the future?		Benefit to environment
		Yes	No	Yes	No	Yes	No	Yes	No	
Phosphorus Feed Utilization										
Formulate and balance ration for Ca: available P ratio										P
Determine available P intake										P
Phytase is being used with supplemental dietary P level reduced										P
By-product feeds are used and formulation adjustments made for their nutrient content and availability										P
Nitrogen Feed Utilization										
Formulate and balance rations on digestible AA ratios										N, NH3
Reduced CP-synthetic AA diets used										N, NH_3
Ingredients selected based on nutrient digestibility										N, NH_3
By-product feeds are used and formulation adjustments made for their nutrient content and availability										N, NH_3
Enzymes used to increase digestibility										N, NH_3

Feed Management Considerations	Has it been implemented?	Was it considered?		Will it be economical?		Will it be implemented?		Will it be considered in the future?		Benefit to environment
		Yes	No	Yes	No	Yes	No	Yes	No	
Ration Management Practices										
Adjust feeders routinely to minimize feed wastage										N, NH_3, P and reduce manure generation
Use proper feed processing methods to maximize nutrient availability										N, NH_3, P
Diet particle size routinely tested										N, NH_3, P
Complete diet provided in pelleted form										N, NH_3, P
Routinely monitor water system and minimize water wastage										N, NH_3, P and reduce manure generation
Use computer feeding system										N, NH_3, P
Quality control procedures used in feed manufacturing										N, NH_3, P
Monitor loading and scale accuracy										N, NH_3, P
New feed ingredient's impact on nutrient efficiency and excretion considered										N, NH_3, P
Formulation safety margins are minimized										N, NH_3, P

Feed Management Considerations	Has it been implemented?	Was it considered?		Will it be economical?		Will it be implemented?		Will it be considered in the future?		Benefit to environment
		Yes	No	Yes	No	Yes	No	Yes	No	
Production Aids/Enhancers										
Antibiotic growth promoters are used										N, NH_3, P
Enzymes are used to improve nutrient digestibility										N, NH_3, P
Paylean										N, NH_3, P
Copper sulfate										N, NH_3, P
Zinc										N, NH_3, P
Organic/ inorganic acids										N, NH_3, P
Vaccination programs										N, NH_3, P
Monitoring Tools										
Monitor N intake/N output										N, NH_3
Monitor water quality for Na, sulfates and nitrates										N, NH_3, P and reduce manure generation
Monitor P intake/P output										P
Measure and record feed intake by phase of production										N, NH_3, P
Monitor feed efficiency by phase of production										N, NH_3, P

Information contained in this checklist assessment was developed by____________________________________ The suggested feeding management practices were the best management practices based on research and professional judgment.

SEGREGATED PARITY STRUCTURE IN SOW FARMS TO CAPTURE NUTRITION, MANAGEMENT AND HEALTH OPPORTUNITIES

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Introduction

This paper presents the rationale for segregating sows on a farm into two age based sub-populations, from a nutritional perspective. The premise is that the amount and type of Nutrients differs for young immature sows (first and second litter) compared to older females (> 4 litters). There is a performance and financial benefit for doing so. Data is presented to show how the number of pigs born per litter and per sow life-time improved by an age specific approach to nutrition. An example format for age segregation and the basis for the partition is provided. This format was implemented in a new 2500 sow farm that Hanor constructed in 2006. This strategy also compliments health and reproductive considerations. This organizational change within the farm is especially important during Lactation as litter-size continues to increase in the modern sow.

Two Extremes in Life-cycle Nutrition of the Sow

The most striking nutritional difference among sow age groups is the amino acid need during Lactation (Boyd et al. 2000; Srichana, 2006). There is substantial evidence for this. There is some difference among age groups during the Gestation phase but this appears to be relatively subtle (**Table 1**). This conclusion is based on growth projections for each reproductive age at mating (PIC USA, 1999), that become the basis for determining minimum daily energy and lysine need to support tissue growth (NRC model for pregnancy, 1998). The primary difference in Gestation appears to be between trimesters with the final 30 d, prior to farrow, being significantly elevated over trimesters 1 and 2 (Dourmad and Etienne, 2002; Srichana, 2006); this being addressed by elevated feed intake. Failure to increase daily intake of energy and nutrients is probably tolerated better by older sows (≥ 3 litters) as compared to younger sows. This relative similarity among reproductive age groups may not be true for micro-nutrients, but hard evidence is needed to confirm this (Boyd, 2004).

Two examples are provided to illustrate how nutrition constrains the expression of genetic potential for litter-size. The first litter female (P-1) is especially vulnerable to body protein loss during Lactation. The foremost consideration is to formulate and feed to conserve body protein loss since there is a direct relationship to both wean to estrus interval (WEI) and second litter-size (Boyd et al. (2000). For example, a 4 kg body protein loss during first lactation is sufficient to reduce second litter-size by 0.75 pigs. Conversely, limiting protein loss to less than 2 kg can result in a 1.0 increase in litter-size, compared to the first. King (1987) illustrated that WEI increases in proportion to body protein loss in young females and that the relationship is relatively high (R^2 0.63). In practice, it is not uncommon for WEI to be extended by ≥ 10 d for the first weaned sow that raised a large litter, milked well and suffered 'too much' protein loss. Unfortunately, this is sometimes interpreted as 'reproductive failure' and may result in early cull from the herd. The alternative consequence is reduced second litter-size, unless management chooses to skip-a-heat to avoid the reduction in litter-size.

The 'Older' female is at risk for a premature decline in litter-size with advancing parity (and perhaps viability), but for different reasons. Total pigs born and born alive increase to the 3rd litter, then are constant until about litter 5 in prolific sow lines; thereafter, a progressive decline is observed (**Figure 1**). Shape of the curve is similar for sows weaned early (15 d) or later (24 d) (Smits, 2003). This parity related decline in litter-size for the prolific sow seems premature from a reproductive perspective (G. Foxcroft personal communication, 2004). The opportunity, is probably in the order of 1.8 to 3.3 pigs per sow life-time, depending on whether productive life-time is 8 or 10 litters. We hypothesize that this is, in part, the result of a progressive decline in micronutrient nutrition as the sow ages. This concept was first proposed by *Boyd (2004).*

Disparity in Micro-nutrient Nutrition for Older Sows

Micro-nutrients consist of Vitamins and Trace minerals (VTM). They represent 0.12 – 0.15% of the diet but about 50% of the Nutrients. In concept, micro-nutrients are formulated in diets at levels that prevent deficiency and include some margin of safety. In practice, there is a steady decline in micronutrient intake with increasing reproductive age, when expressed on a g VTM/kg body weight basis. This assumes that feed level is approximately the same for each age group during Gestation (ca. 2.1 kg/d during trimesters 1-2). This means of controlling body growth with each reproductive cycle (i.e. meeting increasing maintenance needs but progressively limiting growth) is typical because it is the basis for controlling feed cost. The allowance for greater growth rates across ages (and body size) results in cost without a corresponding increase in pig output.

Progressive demineralization is one result of the steady decline in relative micronutrient intake (Mahan and Newton, 1995). This most likely occurs because pregnancy feed intake is held about constant (once body condition has been restored) across all parities to limit growth (e.g., 2.1 kg/d). However, body weight progressively increases with reproductive age. This 'constant' feed procedure is appropriate for protein and energy needs (NRC, 1998; PIC USA, 1999), however, it probably does not work for VTM because the amount that is required to support tissue metabolism presumably increases with the increase in tissue mass. This results in a marked decline in the g VTM / kg body weight with increasing parity (**Figure 2**). The problem is that this occurs with each Pregnancy and it also occurs, albeit to a lesser extent in Lactation. Thus, the older (heavier) sow is placed at an increasing nutritional risk; the consequences could be reproductive and immunologic.

Micro-nutrient Equalization in Older Sows and Litter-size

The first suggestion that an age-dependent decline in litter-size may be nutrition related was derived from a test involving mature sows on two Hanor farms (Boyd, 2004). Two, 10,000 sow farms were used for the study. When each farm was founded (1996), they were organized into 4 quadrants, based on sow age. Each of the 4 quadrants are treated as separate sow 'farms' and have ca. 2650 sows each. Two of the four quadrants have mature and older sows that have had four or more litters. This resulted in a total of four mature sow 'farms' from the two, 10,000 sow farms that could be allocated for test.

A 12-month pre-test period was conducted to characterize each of the four test 'farms' for total pigs born and born alive, sow and pre-wean pig mortality. Two 'farms' were allocated to the Control and two to the VTM-correction treatments from performance blocks. Control sows received 0.15% VTM per usual. Test Sow diets contained additional VTM, choline and chromium using a correction factor of 0.76 for pregnancy and 0.82 for lactation. Average Intake was assumed to be 2.2 kg/d and 5.7 kg/d for Gestation and Lactation respectively. This increase provided the same g VTM / kg body weight for a sow having completed 6 litters as computed for a sow completing 3 litters. The annual cost of this increase was approximately $1.69 per sow (2004 estimate), compared to Control diets. Record evaluation initiated for sows after they completed a Lactation period on Test diets and then continued for a 12 month period. Litter-size weaned was improved with VTM 'equalization' for litters 4 – 10 (0.60 pigs/litter; 1.44 pigs per year) (**Figure 3**). Sow viability was not 'significantly' improved for the term of this study (-0.26%).

Defining Young and Mature Sow Subpopulations

The axiom of 'organizing the sow farm to nutritionally manage maiden and first itter sows and then to adjust Nutrient level for the 'Older' sow' is one that if practiced will increase sow life-time pig output. This was demonstrated using the 1996 Hanor age segregation model, which divided the sow herd into 3 sub-populations (P-0 thru P-1; P-2 thru P-3 and P-4 thru P-12). This practical forum for age segregation study led us to the present template, which is to organize the sow herd into two sub-populations that can be fed and managed with sufficient specificity. Primary outcomes from this Nutrition specific format are: Increased life-time pig output and reduced risk to sow viability with no increase in feed cost per weaned pig.

Table 2a provides a simplified format that we used to identify the 'Young' sub-population from the mature and senior population. This matrix required integration of (1) special nutrition needs over the life-span, and (2) special physiological needs that could be addressed with Nutrients or functional proteins to potentially address a physiological problem such as high embryonic death. Division into two sub-populations was also based on (3) present nutritional knowledge, and (4) anticipated breakthroughs that are needed to improve pigs born alive (immune modulation at key points). Specific examples of age-specific nutrition emphasis are provided in **Table 2b.**

Expected Outcomes for Two Sow Sub-populations

Organization of the sow herd into a 'Young' sub-population, consisting of P-0 through P-2 (2 conceptions) and an 'Older' sub-population, consisting of P-3 through P-10 (3rd - 10th conception) is a reasonable approach to address very different nutritional needs of the Young and 'Geriatric' sows. The expected Outcome is to improve Life-time Pig output by producing a large first litter and then to manage her in a manner that does not compromise 2nd litter size. Once P-1 females are successfully re-bred (P-2) and managed to 30 d pregnant, then the need for specialized 'Young' sow Nutrition probably ends. However, there may be Health-based reasons for keeping 'Younger' sows in this sub-population.

The decision to include P-3,4 sows with the 'Older' sub-population is driven by the need to reduce Gestation and Lactation diet cost. The expected Outcome in this sub-population is to avoid the premature decline in pigs born and weaned, which will add 1.8 to 3.3 pigs per sow life-time. It is not clear whether the relative lower viability of 'Older' sows, compared to Younger sows, can be improved by adjusting Micro-nutrient level and perhaps form. Mature sows can also utilize cheaper ingredient by-products very well. A comparison of annual Feed Cost ($/Sow/Year) is presented in **Table 2** for (1) a Two Sub-population sow farm vs. (2) a Standard sow farm.

The intent of the Mature and 'Older' sow sub-population is to extend productive life by 'Healthy Aging'. Special considerations for the Senior sow probably include declining immune capability and nutrient absorption (or retention efficiency) if sows follow the pattern exhibited in aging dogs and cats [8, 9]. Aging brings about age-associated changes in metabolism and physiology that influence the way 'older' animals utilize nutrients. The decline in Immune capability is esp. noteworthy; the role of Vitamin E (level and form) in improving Immune response to protect against infection is also important. A recent report of animal plasma Functional proteins to improve performance in 'Older' sows can also be accommodated in this 2nd Sub-population [10]. Wound healing and advancing osteoarthritis are likewise considerations that could be more specifically addressed.

Final Thoughts

This paper describes the rationale for organizing a Sow Farm into two sub-populations for age-based feeding. This was shown to improve litter-size in both the 2nd Litter and in Mature - Aging sows. This arrangement is possible for existing Sow Farms, provided that one does not hold onto old paradigms. The strategy was based on Nutritional considerations but we believe that they compliment Health (and Reproductive) objectives with respect to PRRS, Mycoplasma Pneumonia and piglet enteric disease. Inherent in this strategy is that a 'Wean to Breed' row is needed for dedicated feeding to promote litter-size (4 feedings per d). We anticipate that this could evolve into a 'Wean to 30 d Bred' feed strategy if improved embryo viability can result from early pregnancy Immune modulation (based on research in humans and perhaps with plasma functional proteins). The axiom of one Gestation and one Lactation diet is well overdue for change since this practice, albeit easy, has imposed a 'silent' financial cost on systems utilizing prolific sows. Companion animal research is well-advanced compared to Food animals in this area and can serve as a potential means to advance (Hayek et al., 2001; Meydani et al., 2001).

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Table 1. Calculated energy and lysine requirement for prolific sows at different age using the NRC (1998) pregnancy model

Weight at Mating, lbs	Parity	Suggested Gain, lbs	Feed Intake, lbs/d	Feed Intake, kg/d	NRC ME Kcal/d	T Lysine g/d	SID Lysine g/d	SID Lysine %
280	1	75	4.8	2.2	7032	12.3	10.8	0.497
330	2	65	4.9	2.2	7179	12.3	10.8	0.487
385	3	55	4.9	2.2	7275	12.3	10.8	0.487
420	4	45	4.9	2.2	7205	11.9	10.5	0.471
440	5	35	4.7	2.1	7070	11.5	10.1	0.474
450	6	30	4.8	2.2	6930	11.4	10.0	0.460
460	7	25	4.6	2.1	7035	11.1	9.8	0.468

Table 2a. Matrix used to Evaluate the Need for Nutrient Level and Form: Reproductive Age Over the Life-span and at Different Points in the Physiological Cycle of a Pregnancy

	Sow Age in Number Pregnancies					
Item	P-0	P-1	P-2	P-3, 4	P-5	P 6-12
Feed Cost, Gestation (relative cost)	100	100	98	97	97	92
Feed Cost, Lactation (relative cost)	-	100	81	73	65	65
Pre-breed Feed Level	x					
Wean to Bred Feed Frequency (4/d)		x	x	x	x	x
Wean to 30 d Bred, Immune Modulation		x	x	x	x	x
Net Pregnant Growth Promotion		xx	x			
Net Pregnant Growth Restriction				x	x	x
90 d Bred to Farrow, Immune Modulation		x	x	x	x	x
90 d Bred to Farrow, Stillbirth Modulation						x
Lactation Diet for Body Conservation		xx	x			
Mature-Geriatric Life-cycle Nutrition					x	xx

Table 2b. Examples of Nutritional differences that if addressed could create improvement[1, 2]

Sow Age	Potential Nutrition Function or Lysine Level
P 0, Pre-breed Maidens	Feed Induced Ovulation, Growth
P 1	Pregnancy Growth; Lactation Lysine, 1.30%
P 2	Pregnancy Growth; Lactation Lysine, 1.00%
P 3 – 4	Pregnancy Growth restrict; Lactation Lysine, 0.85%
P 5	Life-cycle VTM Correction – Feed cost reduction (highest wheat midds) Obligatory Pregnancy Growth; Lactation Lysine, 0.80%
P 6 -12	Life-cycle VTM Correction; Feed cost reduction (highest wheat midds)
P 1 – 12	Breeding to 30 d Post-coitum; Immune modulation might reduce E. death

[1] 1998 NRC Model estimate for Pregnancy Lysine requirement with a margin included.

[2] 1999 PIC USA Specifications for Lactation Lysine requirement

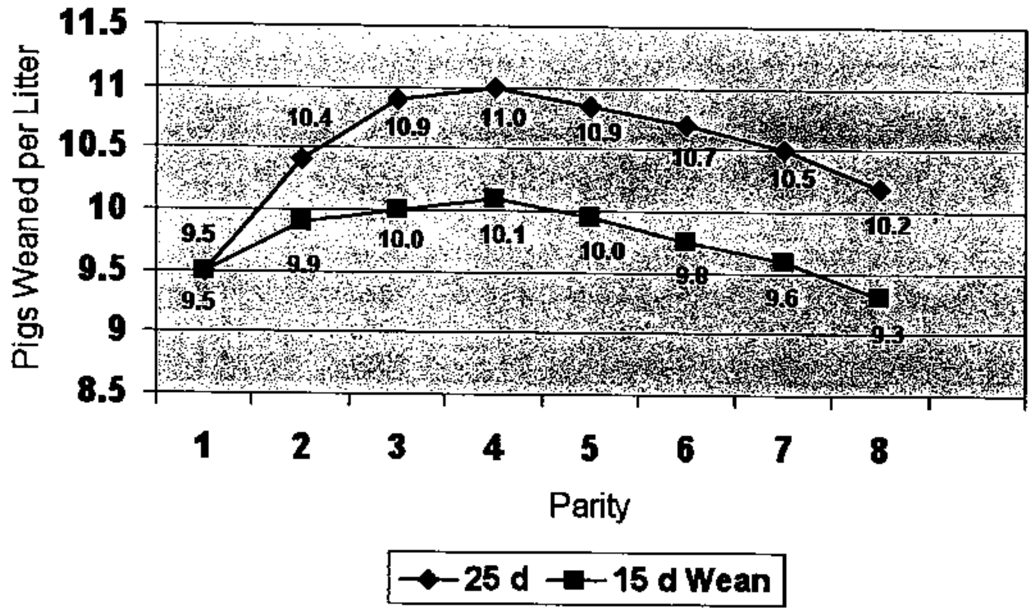

Figure 1. Age-related reduction in litter-size is modulated by lactation length (Pig born alive per litter), Smits, 2003

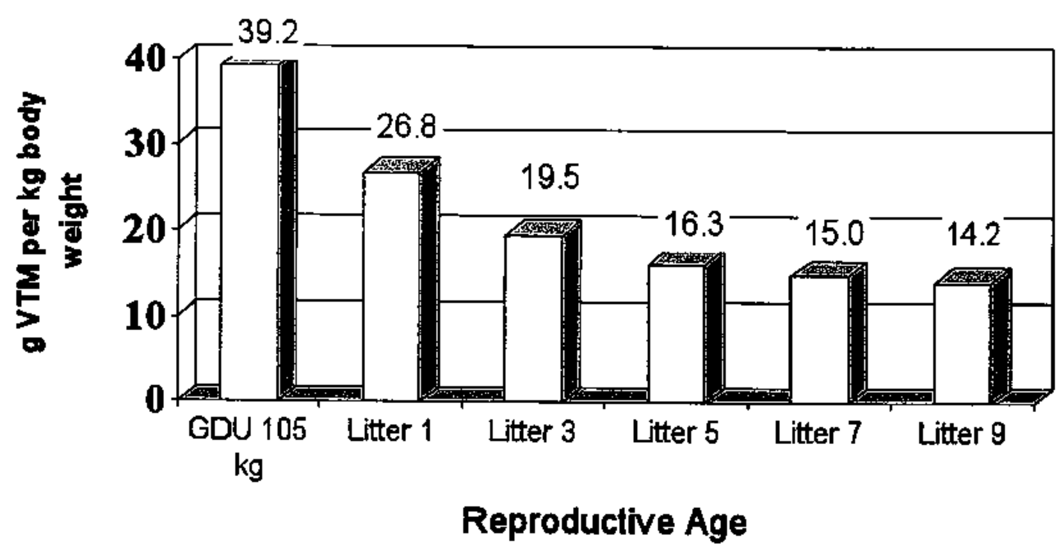

Figure 2. Example Calculation of Declining Vitamin – Trace mineral intake with Advancing Reproductive Age, g VTM / kg body weight (Calculated by Boyd, 2004 using PIC USA 1999 ADFI x Sow weight Parity assuming 0.149% dietary VTM)

Does the Modern Pig Have Different Mineral Compositions and Dietary Needs than Pigs of the Past ?

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SUMMARY

Barrows and gilts differing in their lean tissue growth rate were used to determine the mineral compositions between 2 genetic lines and sexes. Although gilts were leaner than barrows, the greatest difference in lean tissue was between the 2 genetic lines. The high lean genetic line also had greater amounts of macro- and microminerals at 125 kg body weight except for calcium, but total phosphorus was the same for the 2 genetic lines. The low-lean genetic line had more calcium that was attributable to their greater bone mineralization, whereas the similar phosphorus contents were associated with a difference where phosphorus was used (i.e., muscle and bone). Microminerals were greater in the high-lean genetic line. When values are expressed on an amount per kg tissue weight, most of the differences, except calcium, were the same. These results indicate that mineral composition of the pig is largely under genetic control and that mineral composition can be modeled once the relative amount of lean and bone tissue is determined in the various genetic lines.

Introduction

Consumers' desire lean pork of high-quality that can provide a healthy food for their families. The swine industry has met this challenge and has provided such a product. Advances in swine production technologies have dramatically changed over the past 4 decades with the feed and processing industries along with changes in genetic selection practices have resulted in dramatic changes in feeding practices.

Prior to the 1950's lard was a valuable commodity and pigs were selected for their ability in depositing high amounts of fat by market. Genetic selection since that time has not only increased lean muscle and decreased the total body fat content of pigs, but there has been a concurrent and steady increase in slaughter weights. The larger pigs at slaughter have increased dressing percentages by 4.5% and salable retail pork products by 12.5 kg during this time period (NPB, 2000). Although body weight is an important variable in assessing the value of the pig, it is typically used in conjunction with loin eye area (LEA) and backfat depth (BF) to determine carcass merit. Currently over 95% of pigs marketed are sold on a "carcass merit" and the subsequent pricing system reflects this improvement in carcass quality.

Improvements in genetic selection are attributed to results in greater amounts of muscle tissue and less fat, but the mineral component has also changed not only in quantity, but perhaps also in the ratio of the minerals. Most research conducted with the modern pig has dealt with their amino acid and energy needs but few have evaluated the effect on differences in mineral composition and the effects these minerals might have on dietary requirements.

Growth is a complex, dynamic system influenced by various internal and external factors. Genetic line, environment, health, nutrition (feed composition and intake), and body weight can each influence pig growth rate and thus their mineral requirements. The first step in assessing the mineral needs is to determine if body compositions differences occur between pigs of modern lean genetic lines compared to a genetic line with less lean tissue. These findings can then be integrated into computer models for diet formulations to maximize growth, as well as minimizing nutrient waste through proper diet nutrition.

Materials and Methods

The focus of this research was to compare barrows and gilts of two genetic lines with differing lean gain potentials on carcass and mineral composition differences. Two genetic lines of barrows and gilts with the low lean herd lean gain that averaged 280 g fat free lean (FFL)/day was used, while the high-lean genetic line averaged 375 g FFL/day. Diets comprised of corn and soybean meal mixtures that were formulated to their lean gain potential were fed to each genetic line from 20 to 125 kg body weight. Although a total of 120 pigs were killed at periodic intervals from 20 to 125 kg body weight), only the data at 125 kg are presented. Pigs were harvested and carcasses measurements collected, loin and ham muscles were dissected from the animal and analyzed separately from the remaining body components. Total mineral contents were calculated and evaluated for the effect of each genetic line and sex. In addition, in order to differentiate where the differences occurred various body components were analyzed separately.

Results

Although pigs of both sexes of the 2 genetic lines were harvested at periodic body weight intervals from 20 to 125 kg, only the terminal measurements are reported. Thus there was a total of 120 pigs killed over the course of the experiment but only 24 are reported herein. Table 1 presents the carcass and lean tissue measurements of these pigs at market weight. Pigs were killed at a constant body weight in order to make appropriate comparisons. As expected, and as indicated in the results of Table 1, both the high-lean genetic line and gilts had greater LEA and lower BF depths than the low-lean genetic line and barrows. In the genetic lines evaluated there was a greater difference in the various lean tissue measurements between the 2 genetic lines than between the sexes. Loin and the deboned ham muscle masses were greater by over 15% in the high-lean compared to the low-lean genetic line, whereas gilts had approximately 6% greater loin and ham muscle masses than barrows. When the amount of total fat free lean tissue was calculated from carcass measurements, the high-lean genetic line had approximately 10% more total lean than the low-lean genetic line, whereas gilts had approximately 5% more fat free lean tissue than barrows. Although this study was not conducted to compare genetic lines or the sexes on these body lean tissue differences, the data indicate that substantial differences existed between the 2 genetic lines and between barrows and gilts . We would probably have expected gilts to be somewhat leaner than the barrows, but in this particular genetic line these differences did not exist. Further details about the characteristics of these pigs can be located in other publications (Wiseman et al., 2007a, b).

The mineral composition of barrows and gilts from the 2 genetic lines are presented in Table 2. At the terminal 125 kg body weight the high-lean genetic line had greater amounts of macro- and microminerals, except for calcium, phosphorus, sodium and chloride. Both sodium and chloride are associated with blood circulation and thus would be expected to be similar at the same body weights. Potassium is known to be in muscle cells and the greater the amount of muscle tissue the greater would be the potassium. Calcium content was greater in the low-lean genetic line while the total amount of phosphorus was similar between the two genetic lines. The total amount of microminerals in the high lean genetic line was greater than in the low-lean genetic line. Although gilts tended to have more macro- and microminerals than barrows the mineral content differences between the 2 sexes was not great.

The results in the above data set indicate that most of the differences between genetic lines and sexes could be attributed to differences in the amount of lean tissue. In order to more clearly identify why the difference exist between the 2 genetic lines, body components were dissected and analyzed for their mineral contents. Loin and ham muscles were removed from the chilled carcass and the ham muscle deboned and trimmed of subcutaneous fat to better reflect the weights and mineral composition of the muscle masses. The remaining body components including the internal tissue and head constituted the second body component. The combined muscle mass presented in Table 3 clearly indicates that both of these muscle groups had greater weights in the high-lean rather than in the low-lean genetic line. Mineral content of this muscle mass was greater in all macro- and microminerals in the high-lean genetic line. However, because this was a quantitative difference reflecting the total amount of minerals in the muscle mass, the data are also expressed on an amount per kg muscle. The data in Table 2 indicate that when this adjustment for mineral composition is made, the differences between the 2 genetic lines disappear. Thus much of the difference in mineral composition between the 2 genetic lines does not appear to be a difference in the retention of the macro- or microminerals in the muscle tissue, but rather a quantitative difference in the total amount of muscle tissue formed.

When the remainder of the total body mineral composition is determined most of the minerals associated with lean tissue (i.e., potassium, sulfur), except phosphorus was greater in the high-lean genetic line pigs. Only calcium appeared to be greater in the low-lean genetic line. Most of the micromineral contents in this body component were similar between the 2 genetic lines. In agreement with the results presented above for the muscle mass, when the mineral compositions are expressed on an amount of mineral per kg tissue basis, most minerals were the same except for calcium and phosphorus, where each were greater in the low-lean genetic line.

Discussion

Our study demonstrated that pigs with a greater propensity to produce lean tissue have greater total body macro- and micromineral contents than pigs producing less muscle tissue. This indicates that many of the mineral requirements for the modern high-lean genetic line pigs are greater than pigs with lesser lean tissue and probably greater than current NRC (1998) requirements. Although previous pig composition results are similar to those of our study (Shields et al., 1983) our results indicate there is a distinct difference based on the amount of lean tissue development.

There was a difference in the mineral composition between the 2 genetic lines for both macro- and microminerals, but the greatest difference appeared to be in macrominerals, particularly those associated with lean tissue. Although phosphorus is associated with muscle formation and one would suspect that its content would increase as the amount of lean tissue increased, phosphorus is also associated with other body tissue, particular skeletal tissue. In contrast, most of the calcium is found in bone tissue and thus was greater in the remaining body component of the low-lean genetic line. Because P is mutually retained in muscle and other body proteins as well as bone tissue, the relative need for Ca and P for their total requrement may differ by the amount of the different tissues being formed. Both muscle and bone tissues require both calcium and phosphorus for their formation. Because total calcium content is greater in the low-lean genetic line but similar in phosphorus contents, one would suspect that more bone mineralization was taking place in the low-lean genetic line. Such a response was demonstrated (Wiseman et al., 2007b). Thus if mineral needs are influenced by pig compositional and differences in the growth of various tissues, computer models could accurately predict their needs at various periods based on the amount of lean tissue development, whereupon excess fortification levels can be avoided.

Because of the greater amount of bone mineralization occurring in the low-lean genetic line involving both Ca and P, the similar body P contents in these 2 genetic lines is understandable. The greater amount of both calcium and phosphorus in the loin and ham muscle groups in the high-lean genetic line and the greater amount of calcium in the remaining body components of the low-lean genetic line indicates that this response is largely attributed to the retention of P in both muscles and bones. Consequently, both genetic lines would have similar P contents but not Ca contents.

The content of microminerals was also greater in the high-lean genetic line pigs. Further examination of the data indicates that as with the macrominerals, most of the differences could be attributed to the amount of lean tissue being formed. Again, those microminerals with the greater differences between the 2 genetic lines were associated with lean muscle mass.

Expressing the data on an amount per kg tissue weight presents the data on an equivalent weight basis and evaluates the amount of mineral retention occurring as the pig matures to harvest weights. When the macro-and microminerals were expressed in such a manner the results demonstrated that pigs had similar mineral contents per kg tissue except that those with greater amounts of lean tissue had more macrominerals per unit body weight than pigs with lesser lean tissue. In contrast, the micromineral contents were generally similar between the genetic lines and sexes.

It is thus possible that with greater lean tissue growth occurring, particularly during the latter part of the finisher period in the high-lean genetic line that there was an inadequate amount of dietary minerals for deposition or retention in this tissue. Our results imply that the retention of the minerals by body tissue is under genetic regulation, and that when the dietary supply is adequate, the tissue contents would be similar between genetic lines and sexes at the same physiological age. Although NRC (1998) shows a decline in the pigs dietary requirement of macro and microminerals as the pig approaches market weight, our results would indicate that this decline might not be appropriate for pigs of high-lean gain potential.

The amount of minerals needed for the total body reflects not only the amount of the various tissues being developed but the corresponding feed intakes and thus the mineral intake of the pigs.

If we assume that the average potential growth rate of a high lean genetic line pig is 10% greater than pigs having low-lean tissue formation but with similar feed intakes, the dietary mineral nutrient requirements would be greater due to greater lean tissue growth. However, if feed intake was lowered in pigs having high-lean gain potential, as is commonly reported for some high-lean genetic lines, then the dietary requirement would need to be adjusted upward reflecting the feed intake of each genetic line. The provision of anabolic agents (i.e., ractopamine) would further exacerbate the mineral needs of the pigs.

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Table 1. Main effects of carcass characteristics of barrows and gilts of two genetic lines at 125 kg body weight

	Genetic line				Sex			
Item	High lean	Low lean	SED	(P)	Barrow	Gilt	SED	(P)
No. of pigs	12	12			12	12		
Final wt., kg.	126	126	1.5		127	126	1.5	
Hot carcass wt., kg	95.1	94.2	1.1		94.6	94.7	1.1	
Carcass measurements [1]								
Loin eye, inch^2	7.01	5.86	1.3	(.01)	6.50	6.67	0.2	(.01)
Backfat, inch	0.68	0.91	0.2	(.01)	0.84	0.70	0.04	(.01)
Dissected tissue, kg [2]								
Loin muscles	10.4	8.6	0.3	(.01)	9.1	9.8	0.3	
Ham muscles	13.8	11.8	0.3	(.01)	12.3	13.0	0.3	
Fat-free lean, kg [3]	48.6	43.4	1.0	(.01)	44.8	47.2	1.0	(.06)

[1] Measured on chilled carcass at 125 kg.
[2] Dissected from total chilled body.
[3] Calculated from carcass measurements at 125 kg body weight (NPB formula 2000).

Table 2. Macro- and Microminerals compositions of barrows and gilts of two genetic lines at 125 kilogram body weight

	Genetic line				Sex			
Item	High lean	Low lean	SED	(P)[1]	Barrow	Gilt	SED	(P)[2]
No. of pigs	12	12	-		12	12		
Macromineral, g								
Calcium	692	723	41	(.05)	701	714	41	
Phosphorus	456	456	19		450	461	19	
Potassium	240	210	6	(.01)	223	227	6	
Sodium	79	77	3		77	79	3	
Chloride	83	81	2		81	83	2	
Magnesium	27	25	1	(.06)	26	26	1	
Sulfur	157	136	5	(.01)	145	147	5	
Micromineral, mg								
Chromium	71	59	7		56	74	7	
Copper	160	146	20		156	151	21	
Iron	1858	1858	77		1765	1952	77	(.05)
Manganese	22	20	1	(.05)	21	20	1	
Selenium	12	11	0.01	(.01)	12	12	0.01	
Zinc	2264	2216	58	(.01)	2178	2200	58	

[1] Probability of genetic lines and their interaction with body weight.
[2] Probability of barrows vs. gilts.

Table 3. Mineral content of loin plus ham muscle masses of high – and low – lean genetic lines at 125 kg body weight

Item	Total body mineral			Amt/kg wt.		
	High lean	Low lean	SED	High lean	Low lean	SED
Ham plus loin muscle wt., kg	24.2	20.4	-	21.4	22.8	-
Macromineral, g						
Calcium	1.2	0.9	0.04	0.05	0.05	0.01
Phosphorous	50.9	43.1	0.7	2.11	2.12	0.02
Potassium	89.0	75.1	1.2	3.70	3.70	0.03
Sodium	11.8	9.8	0.2	0.49	0.48	0.01
Chloride	11.3	9.6	0.2	0.47	0.47	0.01
Magnesium	5.7	4.8	0.1	0.24	0.24	0.01
Sulfur	49.5	39.7	0.7	2.05	1.95	0.02
Micromineral, mg						
Chromium	8.9	7.8	0.6	0.37	0.37	0.03
Copper	17.6	15.1	0.7	0.73	0.77	0.02
Iron	201.4	181.0	6.7	8.4	8.9	0.85
Manganese	3.5	2.8	0.4	0.14	0.14	0.03
Selenium	3.1	2.5	0.1	0.13	0.12	0.01
Zinc	496.0	438.9	8.8	20.6	21.6	0.65

Table 4. Mineral contents of remaining body components of high – and low – lean genetic lines at 125 kg body weight

Item	Total mineral content			Amt/kg wt.		
	High lean	Low lean	SED	High lean	Low lean	SED
Remaining body components, kg	92.7	87.7	0.07	-	-	-
Macro-mineral, g						
Calcium	691	722	25	7.5	8.2	0.3
Phosphorous	405	412	11	4.4	4.7	0.2
Potassium	151	135	2	1.6	1.5	0.03
Sodium	55	54	1	0.6	0.6	0.02
Chloride	65	65	0.9	0.7	0.7	0.01
Magnesium	39	39	0.8	0.4	0.5	0.01
Sulfur	107	96	2	1.2	1.1	0.03
Micromineral, mg						
Chromium	7.3	7.9	0.3	0.08	0.09	0.01
Copper	140.8	129.0	10.9	1.52	1.47	0.04
Iron	1656.8	1677.1	53	17.9	19.1	0.22
Manganese	18.1	17.2	0.6	0.2	0.2	0.04
Selenium	9.3	8.8	0.2	0.1	0.1	0.08
Zinc	1768.8	1673.2	32	19.1	19.1	0.5

Table 5. Mineral accretion regression equations for high-lean and low-lean genetic lines from 20 to 125 kilogram body weight

Mineral	Genetic line	Regression[1]	Best fitting equation[2]
Macro minerals, g			
Ca	High lean	Q	$Y = 38.60 + 2.273*W + 2.363E\text{-}02*W^2$
	Low lean	Q	$Y = 29.08 + 2..914*W + 2.082E\text{-}02*W^2$
P[3]	Combined	Q	$Y = 16.4534 + 2.6039*W + 6.929E\text{-}03*W^2$
K	High lean	L	$Y = 2.380 + 1.896*W$
	Low lean	L	$Y = 7.798 + 1.623*W$
Na[3]	Combined	L	$Y = 6.9187 + 0.5599*W$
Cl	High lean	C	$Y = 1.399 + 0.9795*W - 5.597E\text{-}03*W^2 + 2.317E\text{-}05*W^3$
	Low lean	C	$Y = 3.985 + 0.7975*W - 3.373E\text{-}03*W^2 + 1.446E\text{-}05*W^3$
Mg[3]	Combined	L	$Y = 0.5159 + 0.1953*W$
S	High lean	L	$Y = -0.6047 + 1.214*W$
	Low lean	L	$Y = 2.515 + 1.0449*W$
Micro minerals, mg			
Cr[3]	Combined	Qt	$Y = 41.526 - 2.907*W + 9.0853E\text{-}03*W^2 - 1.0281E\text{-}03*W^3 + 3.982E\text{-}06*W^4$
Cu[3]	Combined	C	$Y = -15.1696 + 2.3363*W - 3.4033E\text{-}03*W^2 + 1.979E\text{-}04*W^3$
Fe[3]	Combined	Qt	$Y = -871.07 + 93.656*W - 2.0805*W^2 + 2.13888E\text{-}02*W^3 - 7.444E\text{-}05*W^4$
Mn[3]	Combined	Qt	$Y = -6.5485 + 0.9396*W - 2.0101E\text{-}02*W^2 + 2.015E\text{-}04*W^3 + 6.92E\text{-}07*W^4$
Se	High lean	Qt	$Y = -6.859 + 0.6615*W - 1.449E\text{-}02*W^2 + 1.414E\text{-}04*W^3 - 4.635E\text{-}07*W^4$
	Low lean	Qt	$Y = -3.386 + 0.3969*W - 8.200E\text{-}03*W^2 + 7.928E\text{-}05*W^3 - 2.531E\text{-}07*W^4$
Zn	High lean	Qt	$Y = -627.2 + 64.67*W - 1.219*W^2 + 1.190E\text{-}02*W^3 - 3.857E\text{-}05*W^4$
	Low lean	Qt	$Y = -545.5 + 60.69*W - 1.238*W^2 + 1.291E\text{-}02*W^3 - 4.429E\text{-}05*W^4$

[1] Responses of genetic line or genetic line x BW interactions are significant at the regression level indicated (L = linear, Q = quadratic, C = cubic, Qt = quartic).

[2] W = Live body weight, kg.

[3] Combination of the high-lean and low-lean genetic line data when the main effect or the interaction with body weight was not significant.

Efficiency of Utilization of Energy from Protein and Fiber in the Pig – a Case for NE systems[1]

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Summary

An effective use of co-products from the bio-fuel and food industry in pig diets requires a solid understanding of the impact of fiber, protein and ash on energy and amino acid utilization, especially in growing pigs. In any biological system, the efficiency of energy use is determined by both the source of energy and purpose for which energy is used. However, in growing pigs the efficiency of using dietary energy is determined largely by dietary energy source. Current net energy (NE) systems, that predict NE contents from digestible starch, protein, fat, sugar and 'organic residue', provide better predictions of the feeding value of feed ingredients and pig performance than digestible energy (DE) and metabolizable energy (ME) systems, especially when using feed ingredients with extreme nutrient profiles. The application of such NE systems requires a careful characterization of digestible nutrient contents in feed ingredients. In the main current NE systems - the French system developed by Noblet's group and the Dutch National CVB system - there is no need to characterize fiber fractions, as it is represented in the residual 'organic residue' fraction. Differences between the French and Dutch NE systems can be attributed largely to analytical procedures to quantify starch and fat contents and the high estimate for maintenance NE requirements that is used in the French system. When changing from a DE or ME to an NE system, it is useful to confirm that previously determined DE or ME contents are consistent with contents of digestible nutrients and the gross energy content of the respective nutrients. Large discrepancies between previously established DE or ME values and DE or ME values predicted from digestible nutrients contents may necessitate animal experimentation to verify both the DE content and the digestible nutrient contents. Relationships between diet DE, ME and NE contents will vary with ingredient composition and the specific NE system that is chosen. Therefore when changing to an NE system, diet NE specifications that are required for feed formulating are best established by calculating the NE contents of typical diets that were formulated previously using DE or ME systems. When using high dietary levels of fermentable fiber, the pig's threonine requirements are increased, while requirements for lysine, methionine plus cysteine and tryptophan are not altered substantially. When considering fiber and protein effects on energy and amino acid utilization in pigs, feeding values of co-products can be assessed accurately.

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[1]Part of this paper was presented previously. C.F.M. de Lange. 2007. Metabolic use of energy in the growing pig and the practical application of net energy systems. First actualization seminar on the use of crystalline amino acids: Energy efficiency. The Mexican Association of Animal Nutritionists, Querétaro, Mexico. June 25-27, 2007.

Introduction

With increasing energy costs and increased demand of grain starch for food and bio-fuel production alternative sources of energy for use in pig diets should be sought. Co-products from the food and bio-fuel industry generally contain more fiber, protein and ash and less starch. An effective use of these co-products in pig diets requires a solid understanding of the impact of fiber, protein and ash on energy and amino acid utilization, especially in growing pigs.

In this paper the metabolic use of energy from different nutrients and the practical application of current net energy (NE) systems are discussed. Moreover, a few comments are made about the impact of dietary fiber level on amino acid utilization in growing pigs. For a more complete review on energy and amino acid utilization systems for pigs the reader is referred elsewhere (Noblet et al., 1994a; de Lange and Birkett, 2005; Stein et al., 2007).

Characterizing Available Energy Supplied by Nutrients

In any biological system the efficiency of energy use is determined by the source of energy and purpose for which energy is used. This statement implies that for the accurate prediction of animal productivity and feeding value of feed ingredients we need to consider both the dietary energy source and the use of energy by the animal for different body functions (**Figure 1**). This need is further illustrated by the differences in efficiency of deriving available or net energy (**NE**) from digestible energy (**DE**) among the main energy yielding nutrients: starch, protein (**CP**), fat (**CFat**), sugar, and 'organic residue' (**OR**, digestible OR representing fermentable organic material)(**Table 1**). Differences in energetic efficiencies among nutrients can be attributed largely to fermentative, biochemical and metabolic inefficiencies of deriving available energy from digested starch, CP, Cfat and OR, which have been quantified (Noblet et al., 1994a; Van Milgen et al., 2001; Birkett and de Lange, 2001a, b, c; van Milgen, 2002). According to de Lange and Birkett (2005), the impact of dietary energy source on energetic efficiencies in growing pigs is (much) larger than the impact of varying the relative use of energy for different body functions by the animal. Therefore, the focus in this paper is on dietary energy sources and, as a consequence, current empirical NE systems that are based on digestible nutrient contents.

Nutrient analyses. Accurate characterization of the content, and digestibility, of energy yielding nutrient requires strict adherence to well-documented and solid laboratory principles (Sauvant et al., 2004; CVB, 2003). These principles should apply to all aspects of nutrient analyses, including (1) proper sampling and sub-sampling methods; (2) sample processing, such as grinding and, when appropriate, drying; (3) sample storage; and (4) nutrient analyses methods (Boisen and Verstegen, 2000; Moughan et al., 2000).

In particular, close attention should be paid to starch and fat analyses. For starch analyses an enzymatic assay should be used, rather than conventional colorimetric assays (ISO, 2004). According to CVB (2003) the relationship between enzymatically determined starch content (using amylo-glucosidase for hydrolysis of starch, following extraction of simple sugars with 40% ethanol and gelatinizing starch with dimethyl sulphoxide, and measuring glucose appearance; $Starch_{ENZ}$; ISO, 2004) and colorimetrically determined starch content (Ewers method; $Starch_{COL}$) differs substantially between different types of ingredients. For example, for barley $Starch_{ENZ} = 0.975 \times Starch_{COL}$, while for corn $Starch_{ENZM} = 1.024 \times Starch_{COL} - 43.5$ g/kg DM. For ingredients that are high in fat content or that contain substantial amounts of phospholipids, fat extraction should be preceded by acid hydrolysis (Blok, 2006).

The proper and routine characterization of dietary fiber contents, which is closely associated with OR contents, remains a challenge. As discussed in detail in various reviews (Bach-Knudsen, 1997; de Lange, 2000; Noblet and Le Goff, 2001) a large number of chemical and physical measurements have been suggested to determine the content and physical properties of total fiber and different fiber fractions in feed ingredients for mono-gastric animals. Yet, essentially all of these methods fail to account for all organic matter that is not starch, CP, Cfat or sugar (e.g. **Table 2**). From a practical perspective and to account for all energy yielding nutrients in feed ingredients, it is suggested to estimate the dietary fiber content as a residual fraction that represents potentially fermentable substrates (OR)(CVB, 2003; Noblet et al. 1994a). This fraction can be calculated in different ways, all yielding the same value:

Eq. 1: OR = Dry matter – Ash – Starch– CP – Cfat – Sugars

Eq. 2: OR = Organic matter – Starch – Ash – CP – Cfat – Sugars

Eq. 3: OR = Nitrogen-free extract (NFE) + Crude Fiber (CF) – Starch – Sugars

The OR fraction contains a wide range of organic compounds ranging from highly soluble and easily fermentable pectins and oligosaccharides to highly insoluble and poorly fermentable condensed tannins and lignin. It may, however be argued that available energy that pigs may derive from fermentable OR, and via the generation of volatile fatty acids (VFA), is largely determined by its fecal digestibility (i.e. fermentability), and to a lesser extent by types of organic compounds that contribute to digestible OR (Le Goff et al., 2002; Wang et al., 2004; de Lange and Birkett, 2005: Anguita et al., 2006). Birkett and de Lange (2001, a,b) indicated that the efficiency of deriving useful energy from OR varies with VFA profiles that are generated during fermentation, but that in pig studies VFA profiles in the hindgut are reasonably constant across rather extreme diet compositions. The latter is supported by recent studies conducted by Wang et al. (2004), showing that feeding widely different fiber sources to pigs had little impact on the molar ratios among the VFA's that were generated during in vitro fermentation of ileal digesta (**Table 3**). Although it is difficult to experimentally demonstrate that the fermentability, or fecal digestibility, of OR is the main determined of OR's available energy supply to pigs, observations such as those presented in Table 3 would suggest that this is indeed a reasonable assumption. It would be of interest to generate VFA profiles during fermentation of fiber sources that have recently become more available, such distillers grains with solubles (**DDGS**), or to directly and accurately determine their NE value.

Obviously, the accurate estimation of OR content is very sensitive to the analyses of Starch, CP and Cfat contents and, in the case of CP analyses, the assumed relationship between analyzed nitrogen and calculated CP content (Boissen and Verstegen, 2000; Moughan et al., 2000). For many digestibility studies, dietary ash contents and digestibility values are not reported, yet these values are required for the calculation of the fecal digestible OR contents of feed ingredients.

For some extreme ingredients, we may have to further characterize OR in terms of organic acids, alcohol and different fiber fractions. The various fiber fractions, or botanical sources of fiber, may be considered individually when they are associated with effects of animal behavior, and thus energy expenditure, or when the different NSP fractions yield extreme VFA profiles of upon fermentation (Rijnen et al., 2003; Wang et al., 2004). Among fibrous ingredients, only sugar beet pulp has been shown to substantially reduce activity and maintenance energy requirements in growing pigs and sows (Schrama et al., 1998; Rijnen et al., 2003), which may be accommodated in an empirical manner by assigning a NE value to digestible 'organic residue' in sugar beet pulp which is similar to that of starch (CVB, 2003).

Nutrient digestibility. Considerable experimental error may also be introduced in digestibility assays (Bakker and Jongbloed, 1994; Moughan et al., 2000). This can be due to incomplete collections of wasted feed and feces when the total collection method is used. When an indicator method is used to assess digestibility, errors may be associated with improper sampling and determination of marker content in feed and feces. These experimental errors will be amplified when the inclusion level of test ingredients in the feed needs to be limited, due to concerns about palatability or effects of extreme nutrient contents on digestive function, and when regression or substitution methods are used to indirectly calculate digestibility values for ingredients.

Animal factors such as housing, stage of maturity and disease status can have significant impact on energy digestibility and metabolizability (Bakker and Jongbloed, 1994; Le Goff and Noblet, 2001; Rijnen, 2003). For example, in growing pigs, energy digestibility was 2.0 percentage units lower in group-housed pigs than in pigs that were contained in metabolism crates, while metabolizability was 3.7 percentage units lower (Rijnen, 2003; **Table 4**). In particular, the digestive utilization of protein and fat was influenced by housing conditions (Rijnen, 2003), which can likely be attributed to increases in digest passage rate in group-housed pigs. According to the comprehensive studies conducted by Le Goff and Noblet (2001) increases in energy digestibility with stage of maturity (growing pigs versus sows) can be attributed largely to an increased digestive utilization of dietary fat and fiber. It should be noted that reliable databases of energy and nutrient digestibility values established in young pigs with immature digestive systems are still lacking (Noblet et al., 2003; CVB, 2003). The impact of feed processing on digestibility of energy-yielding nutrients has been characterized reasonably well (e.g., Patience et al., 1995; Moughan et al., 2000). However, potential interactions between ingredient type and types of feed processing deserve to be explored further (Noblet et al., 2003; Noblet and van Milgen, 2004).

Evidence from other species, such as ruminants, broiler chickens (Weurding et al., 2003) veal calves (van den Borne et al., 2006), suggest that we should not only consider the absolute or static digestibility of the individual nutrients but also the dynamics of nutrient digestion and absorption. The best 'pig' example to illustrate this point is the observed increase in lysine oxidation and reduction in body protein gain when a diet containing large amounts of synthetic lysine is fed only once a day versus three times per day (Batterham and Bayley, 1989). Up to now, no evidence has been provided that the dynamics of nutrient digestion and absorption influences the efficiency of energy use in growing pigs under typical commercial management conditions. Fledderus et al. (2004) showed that the rate of starch degradability was not related to growth performance and feed efficiency in growing-finishing pigs.

It may be argued that indigestible nutrients should also be considered when estimating the available energy content of feed ingredients. This is to account for the energy cost, or heat losses, associated with nutrient excretion, which may be applicable to co-products that contain large amounts of no-fermentable fiber or ash. However, in a recent study aimed at quantifying the energy costs of fecal excretion of bulk derived from straw, we were unable to detect a decrease in efficiency of generating NE from DE or metabolizable energy (ME)(de Lange et al., 2006a). It remains to be determined, however, whether supplying increased amounts of ash that are supplied with co-products (largely potassium and phosphorus) impacts energetic efficiencies.

Alternative NE systems. It is not practical, and often not even feasible (e.g. for synthetic amino acids), to experimentally determine the NE content of individual feed ingredients. Therefore, a flexible system should be in place that allows accurate estimation of differences in NE contents between different feed ingredients and between different samples of the main feed ingredients.

The preferred means to estimate the NE content of a particular feed ingredient sample is through the use of prediction equations that are based on the apparent fecal digestible content of the energy yielding nutrients (Starch, CP, Cfat, sugar, OR). The use of these variables as independent variables in NE content prediction equations is consistent with our understanding of the 'biology' of energy utilization. Also, there is currently no evidence to suggest that that the amount of NE that pigs derived from each of the energy yielding nutrients varies meaningfully among feed ingredients, provided that feed ingredient effects on nutrient digestibility are considered (e.g. Noblet et al., 1994a; Birkett and de Lange 2001a, b; Fledderus et al., 2004; Noblet and van Milgen, 2004). Therefore, it appears safe to assume that the amount of NE per unit of digestible starch, protein, fat, sugar and OR is constant across a wide range of feed ingredients. Moreover, this approach is consistent with the well-documented NE systems and ingredient values that are currently in use in France and The Netherlands (Sauvant et al., 2004; Blok, 2006).

Ideally, differentiations should be made between enzymatic digestion of starch and protein (largely reflected in measures of apparent ileal digestibility) and fermentation of these nutrients (largely reflected by the difference between apparent fecal and ileal digestibility), but this requires accurate measures of both ileal and fecal nutrient digestibility. However, in most feed ingredients ileal starch digestibility is approaching 100% (CVB, 2003). In ingredients that do not contain substantial amounts of sugars (e.g. less than 5%), sugar contents may be considered part of OR. This simplifies analytical procedures that are required for the prediction of NE contents.

It should be noted that the French NE system was developed based on a colorimetric assay for starch analyses (Sauvant et al., 2004), while the Dutch system is now based on the enzymatic assay (CVB, 2003; Blok, 2006). Recently, the original diet samples from the extensive French NE studies have been re-analyzed for starch content using the enzymatic assay. Based on these updated nutrient analyses a new NE content prediction equation was proposed by Blok (2006) in a European workshop on NE systems for pigs.

In some instances simpler and more empirical prediction equations may be used, but only if equations are based on solid experimental observations that include direct measurements of NE contents, and when estimates are generated for ingredients and diets that are within the range of those for which direct measurements of NE were made. A practical example of limitations of empirical prediction equations is the prediction of DE content of Canadian barley samples from the barley ADF content. Based on determined chemical compositions of 20 barley samples the degree of fit of a simple linear regression related measured DE content to ADF content was found to be acceptable (Fairbairn et al., 1999). However, largely because of its empirical nature, this equation was not appropriate for the prediction of the DE content of wheat (Zijlstra et al., 1999). Instead, the prediction of DE content from the content and digestibility of energy yielding nutrients is, based on first principles, applicable to both wheat and barley.

Rather than estimating NE contents from digestible nutrients, NE contents may be predicted from DE or ME contents with adjustments for digestible nutrients contents. The latter approach may be more acceptable to individuals that are very comfortable with DE or ME systems and reluctant to change to an NE system. Within this context it should be noted that the efficiency of using energy from digestible CP (i.e. 'protein DE'), but not 'protein ME', for either body protein deposition or body lipid deposition (Figure 1) is similar (van Milgen et al., 2001). Apparently, heat losses associated with using digestible CP for body protein synthesis and supporting body protein turnover are similar in magnitude to heat losses plus urinary energy losses associated with using digestible protein for body lipid deposition, i.e. energy cost of de-amination of amino acids, urinary nitrogen excretion, transformation of carbon skeletons from amino acids to fatty acids, lipid synthesis and turnover. In other words, when estimating the available energy (NE) value of digestible protein for growing pigs, no information is needed on the proportion of digestible protein intake that is used for body protein gain or, alternatively, as a source of energy and contributing to urinary energy excretion. This implies that the adjustment of feed ingredient DE content for energy supplied from digestible CP is more robust, i.e. applicable to a wider range of animal states and more likely to be additive in mixtures of feed ingredients, than the adjustment of feed ingredient ME content for energy supplied from digestible CP.

Practical Application of Current NE Systems

In spite of the limitations and methodological concerns about NE systems (de Lange and Birkett, 2005), the use of a well-tested NE system will yield better predictability of pig growth performance than conventional DE and ME systems (e.g. Noblet et al., 1994a; Noblet and van Milgen, 2004). For example, both the French and the Dutch NE systems illustrate the changes, and improved accuracy, in representing relative useful energy contents of feed ingredients when moving from a DE or ME to an NE system for pigs (Table 5). Obviously, the value of NE based feed formulation systems increases with the number of available feed ingredients, especially when feed ingredients vary considerably in contents of digestible Cfat and CP, and fermentable OR.

Five steps should be considered when implementing a NE system for pigs: (1) properly characterize the digestible nutrient content in pig feed ingredients; (2) re-predict current DE or ME contents of feed ingredients from digestible nutrients (Table 1), to confirm that digestible nutrient contents are estimated accurately, (3) choose an appropriate NE equation based on digestible nutrient, (4) establish diet NE specifications for feed formulation and (5) assess pig responses to gain confidence in the NE system. These steps have been discussed in detail elsewhere at the 2007 energy symposium in Mexico (de Lange, 2007; Stein, 2007, van Milgen, 2007) and only key points are mentioned here.

According to Noblet et al. (1994a) diet NE contents (kJ/kg) can be predicted from different combinations of diet characteristics (g or kJ/kg):

Eq. 4: NE = $11.3 \times$ (dig. CP) + $35.0 \times$ (dig. CFat) + $14.4 \times$ starch +
$0 \times$ (dig. ADF) + $12.3 \times$ (dig. OR*) (equation 1; $R^2 = 0.96$; RSD = 201)
(*definition of organic residue varies from the one provide in this text)

Eq. 5: NE = $0.700 \times$ DE + $6.73 \times$ Cfat + $2.00 \times$ starch – $3.81 \times$ CP
– $3.64 \times$ ADF (equation 5; $R^2 = 0.97$; RSD = 176)

Eq. 6: NE = 12029 + $18.3 \times$ Cfat + $2.80 \times$ starch – $23.0 \times$ ash – $8.41 \times$ (NDF-ADF) –$16.8 \times$ ADF (equation 11; $R^2 = 0.93$; RSD = 272).

These equations can be compared to those for predicting diet NE content from diet digestible nutrient contents according to the Dutch NE system (CVB 2003; Blok 2006):

Eq. 7: NE_{2005} = $10.8 \times$ (dig. CP) + $36.1 \times$ (dig. Cfat) + $13.7 \times$ (ileal dig. Starch) +
+ $12.3 \times$ (ileal dig. Sugars) + $9.6 \times$ (dig. OR).

This equation is consistent with the following equation based on the French NE system, provided that it is assumed that starch and sugar are always completely digested (Noblet, 2006; Table 1):

Eq. 8: NE_{g2} = $12.1 \times$ (dig. CP) + $35.0 \times$ (dig. Cfat) + $14.3 \times$ (total Starch) +
+ $11.9 \times$ (total Sugars) + $8.6 \times$ (dig. OR).

In the Dutch NE system a more elaborate equation is applicable for ingredients that contain organic acids and alcohol (CVB, 2003).

Obviously, the prediction of diet NE content from total diet nutrient levels requires less information than prediction from diet digestible nutrient contents. However and as discussed in the previous section, the latter is more accurate and more robust for predicting NE contents of individual feed ingredients, especially ingredients with extreme nutrient contents (CVB, 2003, Blok, 2006). Moreover, within ingredients, nutrient digestibility may be adjusted with changes in animal state, feed processing or origin of feed ingredients (CVB, 2003).

It is important to note that NE values for the main pig feed ingredients according to the French NE system (Noblet et al., 1994a) correlate well with the Dutch NE system (CVB 2003, 2005; Table 5), even though the absolute NE values are systematically higher for the French NE system. The latter can be attributed largely to the relatively high estimate of maintenance NE requirements in the French NE system (de Lange et al., 2006a) and should be reflected in (factorial) estimates of NE requirements for different groups of pigs (de Lange and Birkett, 2005). As mentioned earlier, different methods that are used for nutrient analyses may have contributed to differences between these two systems as well. Both the French and the Dutch NE systems illustrate the changes, and improved accuracy, in representing relative useful energy contents of feed ingredients when moving from a DE to an NE system for pigs (Tables 1 and 5).

Based on first principles (Table 1), equations may be derived to estimate NE contents from DE contents and digestible nutrient contents that are consistent with Eq. 7 and 8:

Eq. 9: $NE_{2005} = DE \times 0.703 - 5.58 \times (\text{dig. CP} - 140) + 8.48 \times (\text{dig. Cfat} - 23) + 1.51 \times (\text{ileal dig. Starch} - 478) + 0.39 \times (\text{ileal dig. Sugars} - 24) - 1.79 \times (\text{dig. OR} - 82)$.

Eq. 10: $NE_{g2} = DE \times 0.728 - 4.86 \times (\text{dig. CP} - 140) + 6.40 \times (\text{dig. Cfat} - 23) + 1.67 \times (\text{Starch} - 478) - 0.33 \times (\text{Sugars} - 24) - 3.19 \times (\text{dig. OR} - 82)$.

(Units of energy are kJ/kg and nutrient contents are in g/kg; either in DM or as fed)

This approach may be useful when changing from DE to NE systems and when there is a large amount of confidence in DE contents of feed ingredients. Here the impact of changing the digestible nutrient content is considered, relative to a standard reference diet. For North American conditions, the reference diet can be a 16% CP containing corn and soybean meal-based diet that contains 2.5% premix (14,197 kJ/kg DE; 140 g/kg dig. CP, 23 g/kg dig. Cfat, 478 g/kg ileal dig. starch, 24 g/kg ileal dig. sugars, 82 g/kg dig. OR; 9,978 kJ/kg NE_{2005}; 10,333 kJ/kg NE_{g2}). The regression coefficients represent the ratio between NE and DE in the reference diet (0.703 in the NE_{2005} from CVB and 0.728 in NE_{g2} the French NE system), and for each digestible nutrient its NE content minus its DE content multiplied by the NE to DE ratio in the reference diet (Table 1). The regression coefficients for the individual nutrients represent their contribution to diet NE in kJ per g change in content, over and above changes in diet DE content. As per the discussion in the previous section in the prediction of available energy from DE or ME and digestible nutrient contents, such an approach would not work when predicting NE from ME values, especially when changing dig. CP levels in the diet.

Based on NE_{2005} (Eq. 7 and 9), replacing 100 g/kg of ileal digestible starch with 60 g/kg of fecal digestible OR (plus 40 g/kg on indigestible material) will decrease diet NE content by 794 kJ/kg (8.0% relative to the reference diet), while diet DE content, calculated from digestible nutrient contents (Table 1) will be 763 kJ/kg lower (5.4% relative to the reference diet). Similarly when replacing 100 g/kg of ileal digestible starch with 85 g/kg of digestible protein (and 15 g/kg indigestible protein), the calculated diet NE content is decreased by 452 kJ/kg (- 4.5%), while the diet DE content is increased by 245 kJ/kg (+ 1.7% increase). The latter is highly consistent with experimental observations reported by van Milgen et al. (2001), who determined directly the DE, ME and NE contents of digestible nutrients.

From a practical perspective this means that feed efficiency, largely driven by diet NE content in diets with similar amino acid to energy ratios, would become about 5% poorer when replacing dietary starch with protein, even though diet DE content would slightly increase. In addition, heat production increases in pigs that are fed diets with increasing amounts of energy supplied from digestible protein, even when the dietary content of the first limiting amino acid is not altered (Le Bellego et al., 2001). Especially, when pigs are under heat stress, an increase in dietary protein content will also reduce daily (net) energy intake, resulting in slight reductions in growth rates and leaner carcasses. The reverse is the case when dietary protein sources are replaced with synthetic amino acids.

Due to variability in diet nutrient composition and assumed animal state, the relationship between estimated diet NE content and either diet DE or ME content will vary with diet composition, pig type, and between NE systems. Therefore, when changing from a DE or ME to NE system, diet formulation specifications for NE are best established by calculating the diet NE content of local and typical diets that have been (least-cost) formulated previously using DE or ME systems. Specifications for all other nutrients, such as standardized ileal digestible (SID) amino acid contents, should not be altered. To evaluate the potential savings of implementing a NE system, least-cost formulate the diets based on the calculated NE content of diets that were formulated previously based on a DE or ME system, and monitor changes in nutrient costs. The change in ingredient composition will vary with available feed ingredients and costs, but will likely include a reduction in diet protein content, an increase in the use of synthetic amino acids, an increase in the use of fat, and possibly an increase in the use of high-fiber co-products.

The ultimate test for any feed ingredient evaluation system is its ability to predict animal performance. In their review, Noblet and van Milgen (2004) have reported various studies that have demonstrated that the French NE system is more accurate that conventional DE and ME systems to predict performance of growing-finishing pigs. Similarly, Rijnen et al. (2004) demonstrated the value of applying the Dutch CVB NE system in practice.

Additional Considerations:

Impact of Dietary Fiber on Amino Acid Utilization

When evaluating alternative pig feed ingredients many factors should be considered, including available nutrient content, product consistency, ease of handling and processing, impacts on voluntary feed intake, carcass dressing percentage, animal production quality and, ultimately, cost. For further information on feed ingredient evaluation the reader is referred to Moughan et al. (2000). In our laboratory we have recently shown that diet effects on utilization of SID digestible intake in growing pigs should also be considered as well, especially in high-fiber containing ingredients.

The apparent ileal digestibility assay, and more recently the SID assay, is used widely as a means to estimate of amino acid bio-availability in feedstuffs for pigs (Stein et al., 2007). When using SID values in feed formulation it is implicitly assumed that there is no effect of dietary amino acid source on the utilization of SID amino acid intake for the various body functions, such as body protein deposition or milk protein production. There is now substantial evidence to suggest that this assumption is incorrect. For example, in pigs fed a wheat shorts containing diet, the utilization of SID lysine and threonine intake for body protein deposition was lower than pigs fed casein based diets (**Figure 2**). Other researchers have made similar observations (e.g. Beech and Batterham, 1991; Grala et al., 1997). The mechanisms whereby dietary protein source influences utilization of SID amino acids appears to be different for lysine and threonine. Non-reactive lysine appears to be an important reason for reductions in the efficiency of lysine utilization in heat treated feed ingredients such as DDGS (Fontaine et al., 2007), while soluble fibre and microbial fermentation in the gut contributes to reductions in the efficiency of threonine utilization (Zhu et al., 2005; Libao-Mercado et al., 2006). Apparently, enteric fermentation, induced with feeding additional fermentable fiber, increases mucin production, especially in the hindgut of pigs. Given the high threonine content in mucin protein, the impact of feeding fermentable fiber on amino acid utilization would be larger for threonine than other amino acids (Libao-Mercado et al., 2007). The latter was confirmed in a series of N-balance studies (Zhu et al., 2005, 2007). Based on the linear relationship between dietary level of added pectin and whole body N-balance (Zhu et al., 2005) it may be estimated that the SID threonine requirements increase with 0.42 g per 100 g of additional fermentable OR intake. Zhu et al. (2005) observed that utilization of SID lysine intake was not influenced by dietary pectin level and that insoluble and non-fermentable fiber (cellulose) had no impact on SID lysine and threonine utilization. More recently, Zhu et al. (2007) observed only minor impact of dietary pectin level on utilization of SID methionine plus cysteine and SID tryptophan for body protein deposition. The impact of fermentable fiber intake on SID threonine requirements should be considered when feeding high fiber containing co-products to pigs. For example, in growing-finishing pigs dietary fiber level has a larger impact on the optimum dietary SID threonine to SID lysine ratio than BW.

Conclusions and Implications

In growing pigs the efficiency of using dietary energy is determined largely by dietary energy source. Current net energy (NE) systems, that predict NE contents from digestible starch, protein, fat, sugar and 'organic residue', provide better predictions of the feeding value of feed ingredients and pig performance than digestible energy (**DE**) and metabolizable energy (**ME**) systems, especially when using feed ingredients with extreme nutrient profiles. The application of such NE systems requires a careful characterization of feed ingredients in terms of nutrient content, especially starch and fat, and digestibility. In the main current NE systems - the French system developed by Noblet's group and the Dutch National CVB system - there is no need to characterize fiber fractions, as it is represented in the residual 'organic residue' fraction. The French NE system provides systematically higher estimates of NE contents in feed ingredients than the Dutch system. When changing from a DE or ME to an NE system, it is useful to confirm that previously determined DE or

ME contents are consistent with contents of digestible nutrients and the gross energy content of the respective nutrients. Relationships between diet DE, ME and NE contents will vary with ingredient composition and the specific NE system that is chosen. Therefore, when changing to an NE system, diet NE specifications that are required for feed formulating are best established by calculating the NE contents of typical diets that were formulated using DE or ME systems. When using high dietary levels of fermentable fiber, the pig's threonine requirements are increased, while requirements for lysine, methionine plus cysteine and tryptophan are not altered substantially. When considering fiber and protein effects on energy and amino acid utilization in pigs, feeding values of co-products can be assessed accurately.

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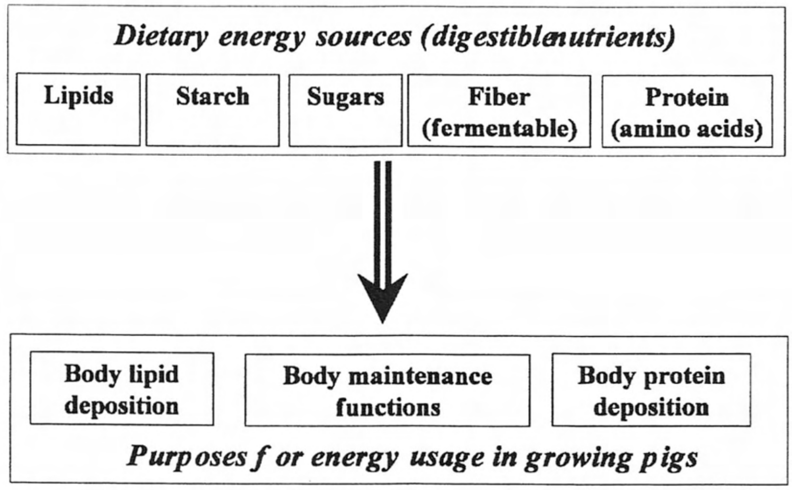

Figure 1. Dietary energy sources and usage of energy by growing pigs.

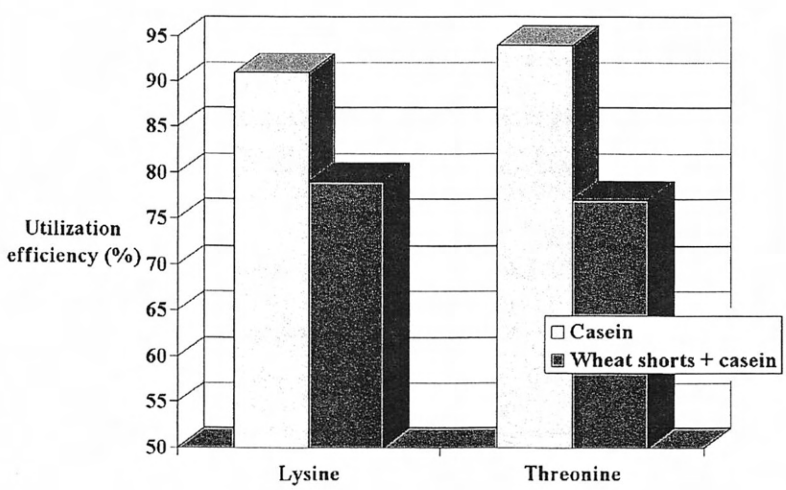

Figure 2. Efficiency of using standardized ileal digestible lysine and threonine intake above maintenance requirements for retention in whole body protein in growing pigs fed casein or wheat shorts + casein based diets that were limiting in either lysine or threonine. Derived from Libao-Mercado et al. (2006) (SEM <1.9).

Table 1. Regression coefficients (J/g) used to predict DE and NE contents in pig feed ingredients from digestible nutrients content

	DE[1]	NE_{g2} (Noblet, 2006)		NE_{2005} (CVB; Blok, 2006)	
		coefficients	NE/DE	coefficients	NE/DE
Digestible starch	17.35	14.3[2]	0.82	13.7[3]	0.79
Digestible crude protein	23.3	12.1	0.48	10.8	0.46
Digestible crude fat	39.3	35.0	0.89	36.1	0.92
Digestible sugars	16.8	11.9[2]	0.71	12.3[3]	0.73
Digestible organic residue	16.2	8.6	0.53	9.6	0.59

[1]Based on gross energy content of digestible nutrients (Birkett and de Lange 2001a).
[2]Based on total content rather than fecal digestible content.
[3]Based on ileal (enzymatically) digestible content, rather than fecal digestible content.

Table 2. Contents (g/kg as fed) of crude fiber (CF), acid detergent fiber (ADF), neutral detergent fiber (NDF) and organic residue (OR)[1] in selected feed ingredients[2]

	CF	ADF	NDF	OR	NDF/OR[3]
Corn	22	27	103	108	0.95
Wheat shorts	70	89	298	321	0.93
Dried distillers grains with solubles	77	139	242	422	0.57
Soybean meal (47% CP)	37	47	89	226	0.39
Canola meal (33.5% CP)	119	185	244	350	0.70

[1]Calculated as dry matter – ash - starch – sugars – CP - Cfat.
[2]Derived from CVB (2003).
[3]NDF as a proportion of OR.

Table 3. Molar ratios among volatile fatty acids (%) after 48 incubation of ileal digesta of pigs fed different fiber sources[1]

	Control	+ 9.4% Potatoe starch	+ 11.8% Sugar beetpulp	+ 19.4% Wheat bran	SEM
Acetate	52.3[a]	53.6[a]	60.1[b]	55.5[a]	1.5
Propionate	23.2[a]	22.5[a]	23.1[a]	27.9[b]	0.9
Butyrate	13.5[a]	15.5[b]	12.0[a]	10.0[c]	0.6
Valerate	5.6	5.9	2.6	3.6	0.7

[1]Derived from Wang et al. (2004); the different fiber sources were included at the indicated levels in the diet and replacing primarily cooked rice and casein.
[a,b,c]Values within rows followed by different superscripts differ.

Table 4. Nutrient digestibility and energy utilization in growing pigs as influenced by housing conditions[1]

	Housing condition				
	Individual	Group	% Change	SEM	P-value
Apparent fecal digestibility, %					
Dry matter	88.6	87.0	-1.9	0.1	<0.001
Ash	51.6	49.9	-3.2	0.4	0.018
Crude protein	87.7	82.6	-5.8	0.4	<0.001
Crude fat	69.5	63.3	-8.9	1.3	0.007
Neutral detergent fiber	72.6	71.3	-1.7	0.4	0.032
Energy	89.9	87.9	-2.2	0.1	<0.001
Energy metabolizability[2], %	94.6	92.5	-2.2	0.4	0.001
RE : ME[3]	0.343	0.338	-1.3	-	-

[1]Derived from Rijnen (2003). Pigs with a mean initial body weight of 44 kg were housed individually in metabolic crates with a floor space of 0.9 m^2, allowing the pigs to turn around, or in groups of 14 pigs with the same amount of floor space per pig. Pigs were fed restricted either a wheat, soybean meal and corn starch based diet or a wheat soybean meal, corn starch based diet with 17% beetpulp. There were no interactions between housing system and diet type (P>0.29).
[2]Determined diet metabolizable energy (ME) content divided by diet digestible energy content.
[3]Determined rate of body energy retention (RE) divided by ME intake; this parameter was calculated from information provided by Rijnen (2003).

Table 5. Estimated net energy (NE) contents (MJ/kg) of selected pig feed ingredients according to Noblet et al. (1994a) and CVB (2003). For comparison diet digestible energy (DE) and metabolizable energy (ME) contents are provided as well[1]

	NE		DE[4]	ME[5]
	Noblet (2006)[2]	CVB (2003)[3]		
Corn	11.21 (100)[6]	10.87 (100)	14.45 (100)	14.11 (100)
Wheat	10.14 (90)	9.75 (90)	13.56 (94)	13.15 (93)
Barley	9.59 (87)	9.30 (86)	12.85 (89)	12.48 (88)
Wheat shorts	7.59 (69)	7.44 (68)	11.05 (76)	10.57 (75)
DDGS	8.62 (78)	8.63 (79)	13.85 (96)	13.09 (93)
Peas	9.73 (85)	9.46 (87)	14.41 (100)	13.78 (98)
SBM (47.5% CP)	8.64 (76)	8.25 (76)	15.44 (107)	14.19 (101)
Canola meal	6.45 (56)	6.23 (57)	11.69 (81)	10.76 (76)
Animal fat	30.93 (273)	31.90 (293)	34.73 (240)	34.54 (245)
Vegetable oil	33.08 (292)	34.12 (314)	37.15 (257)	36.96 (262)
Whey	10.05 (88)	9.95 (92)	14.55 (101)	14.12 (100)

[1]To eliminate impact of ingredient quality, for each ingredient digestible nutrient contents are the same across systems and taken from CVB (2003).
[2]Based on equation NEg2 according to Noblet (2006; Table 1)) and digestible nutrient contents of ingredients according to CVB (2003).
[3]Based on equation NE_{2005} according to Blok (2006; Table 1)
[4]Based on enthalpy of digestible nutrients according to Birkett and de Lange (2001a; Table 1).
[5]Calculated from DE and digestible CP content, assuming that 50% of protein contributes to urinary nitrogen excretion and urinary energy (MJ/kg feed) excretion is 0.19 + 0.03 x urinary N (g /kg feed).
[6]Values in brackets and within columns are energy values relative to corn.

Use of Novel Soybean Products for Swine

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Summary

Traditional plant breeding has resulted in the development of new high-protein varieties of soybeans that contain 46 to 48% crude protein. Soybean meal produced from these beans contains 56 to 58% crude protein and approximately 3.5% lysine. The digestibility of amino acids in high protein soybeans and in high protein soybean meal is comparable to that of conventional varieties, but because of the increased protein and amino acid concentration, more digestible amino acids are present in high protein soybeans and high protein soybean meal compared with conventional sources of soybeans and soybean meal. The inclusion rate of soybean meal can, therefore, be reduced if high-protein soybean meal is included in diets fed to swine in stead of conventional soybean meal. The concentration of digestible and metabolizable energy in high protein soybean meal is also greater than in conventional soybean meal. Low oligosaccharide varieties of soybeans have also been developed and soybean meal from these varieties contains fewer oligosaccharides, but more amino acids, than conventional soybean meal. The digestibility of amino acids and energy in low oligosaccharide soybean meal is comparable to conventional soybean meal. Fermentation of soybean meal in the presence of bacillus strains or treatment by enzymes results in soybean meal that contains no antigens, oligosaccharides, or sugars, but greater concentrations of amino acids than conventional soybean meal. These new sources of soybean meal are believed to be better tolerated by young pigs than conventional soybean meal and may be used in diets fed to weanling pigs in stead of animal protein sources.

INTRODUCTION

Novel soybean products that are available to the feed industry include products that are produced from new varieties of soybeans as well as products that are a result of novel processing technologies applied to harvested soybeans. New varieties of soybeans are produced by modifying the genetic make-up of soybeans using biotechnological tools ("GMO-soybeans") or by using traditional plant breeding technologies (Stein et al., 2008). Genetic modification using biotechnology has primarily focused on modifying input traits by insertion of genes that infers *in planta* glyphosate tolerance to soybeans ("Round-up Ready" soybeans), whereas traditional plant breeding technologies primarily have been used to enhance output traits (Parsons, 2000). Modification of input traits of soybeans does not change the composition or the nutritional value of the soybeans or the soybean meal produced from these beans (Cromwell et al., 2002). In contrast, modification of output traits may change the composition of the beans as well as the nutritional value of the soybean meal produced from these beans (Baker and Stein, 2008; Cervantes-Pahm and Stein, 2008). Likewise, introduction of novel processing technologies that are applied to harvested soybeans may result in changes in both composition and nutritional value of the soybean meals that are produced.

It is the objective of this contribution to review current knowledge about new soybean products that are available to the feed industry as a result of changes in the genetic make-up of the beans and in post-harvest processing of soybeans.

COMPOSITION OF SOYBEANS AND SOYBEAN MEAL

Conventional soybeans contain on a DM basis approximately 41% crude protein, 5% ash, 18% acid hydrolyzed fat, and 34% carbohydrates (Table 1; Grieshop et al., 2003). Approximately 44% of the carbohydrates are nonstructural carbohydrates (Grieshop et al., 2003). The concentration of free glucose, galactose, and fructose is low, but soybeans contain 4 to 5% sucrose, 4 to 5% oligosaccharides, and 3 to 4% uronic acid (DM-basis). The oligosaccharides are alpha-galactosides and consist mainly of stachyose, although raffinose and verbascose are also present in soybeans, but at a concentration of less than 1% (Grieshop et al., 2003). Most of the fat is removed during crushing and soybean meal contains usually less than 5% ether extract. Soybeans are usually also de-hulled during crushing, which results in a reduced concentration of non-starch polysaccharides in soybean meal (Table 1; Grieshop et al., 2003). In contrast, soybean meal contains more protein, more ash, and more non-structural carbohydrates than soybeans (approximately 54, 7.5, and 20% (DM basis), respectively). The concentration of alpha-galactosides in soybean meal is between 6 and 7% (DM basis), and stachyose is usually 80 to 85% of all alpha-galactosides. On a DM basis, soybean meal also contains 6 to 7% sucrose and 3 to 4% uronic acid (Grieshop et al., 2003).

MODIFICATION OF SOYBEAN COMPOSITION

Most efforts in terms of changing the composition of soybeans have been directed towards increasing protein concentration and reducing the concentration of oligosaccharides in soybeans. New varieties of high protein soybeans that contain 45 to 48% crude protein (as-is basis) have been introduced and the concentration of amino acids in these high protein beans is increased to the same degree as the concentration of crude protein (Table 2; Cervantes-Pahm and Stein, 2008). The standardized ileal digestibility of amino acids in full-fat high protein soybeans is similar to that of conventional full-fat soybeans (Table 3), which means that the concentration of digestible amino acids in high-protein soybeans is increased to the same degree as the concentration of total amino acids. When high protein soybeans are crushed, a soybean meal containing 56 to 58% crude protein (as-is basis) is produced (Table 2; Baker and Stein, 2008). This soybean meal contains approximately 3.5% lysine and the standardized ileal digestibility of amino acids in high-protein soybean meal is comparable to the digestibility of amino acids in conventional soybean meal (Table 3). The concentration of digestible amino acids in high protein soybean meal is, therefore, increased to the same degree as the concentration of total amino acids. In addition, because of the increased concentration of protein, high protein soybean meal also has a greater concentration of digestible and metabolizable energy compared with conventional soybean meal (Baker and Stein, 2008).

To reduce the negative impact of the alpha-galactosides that are present in normal soybeans and soybean meal produced from conventional soybeans, new beans with a low concentration of oligosaccharides have been bred. Soybean meal from these low oligosaccharide soybeans has a lower concentration of oligosaccharides, but a greater concentration of crude protein and amino acids than conventional soybeans (Baker and Stein, 2008). The standardized ileal digestibility of amino acids in low-oligosaccharide soybean meal is comparable to that of conventional soybean meal (Baker and Stein, 2008). Likewise, the concentration of digestible and metabolizable energy in low-oligosaccharide soybean meal is similar to the concentration in conventional soybean meal (Baker and Stein, 2008).

FURTHER PROCESSING OF SOYBEAN MEAL

Enzymatically treated or fermented soybean meal

In diets fed to growing-finishing and reproducing swine, all amino acids needed by the animals may be provided by soybean meal. However, newly weaned pigs do not tolerate soy protein as well as older pigs (Sohn et al., 1994), and they may develop allergenic reactions followed by immunological responses if they are fed large quantities of SBM (Li et al., 1990; 1991). It is, therefore, common practice to limit the inclusion of soybean protein in diets fed to weanling pigs and more expensive animal protein sources such as milk protein, fish meal, and blood proteins are used as the primary sources of amino acids in these diets. However, two new soybean products, HP 300 and PepSoyGen, respectively, that are expected to be devoid of soy allergens were recently introduced to the North American marked. It is believed that these products can be included in diets fed to weanling pigs without causing adverse allergenic reactions.

During the production of HP 300 (Hamlet Protein, Horsens, Denmark), a proprietary enzymatic preparation is used to digest the antigens in soybean meal. The oligosaccharides and sugars in the soybean meal are also removed and the resultant soybean meal contains approximately 53% crude protein (Table 4; Zhu et al., 1998; Pahm, 2008). The digestibility of amino acids in HP 300 is greater than in conventional soybean meal (Table 5; Pahm, 2008). Numerous experiments in Europe and Asia have demonstrated that inclusion of HP 300 in diets fed to weanling pigs results in pig performance that is similar to that obtained on diets based on animal proteins, but at this point, no data from the US are available.

PepSoyGen (NutraFerm, North Sioux City, SD) is produced by fermentation of soybean meal in the presence of *Apergillus oryzae* and *Bacillus subtillis*. Antigens, antinutritional factors, oligosaccharides, and sugars are removed from the soybean meal during fermentation (Table 4; Hong et al., 2004; Yang et al., 2007; Pahm, 2008). The proteins in the soybean meal is also hydrolyzed during fermentation, which results in reduced peptide size in PepSoyGen compared with conventional soybean meal (Hong et al., 2004). PepSoyGen contains approximately 10% more protein than conventional soybean meal, but the amino acid sequence is similar to the sequence in conventional soybean meal (Hong et al., 2004). The standardized ileal digestibility of amino acids in PepSoyGen is similar to the digestibility in conventional soybean meal (Table 5; Pahm, 2008), but the inclusion of PepSoyGen in diets fed to weanling pigs at the expense of conventional soybean meal improves pig performance (Feng et al., 2007). It is, therefore, possible that PepSoyGen can be used in weanling pig diets as a substitute for more expensive animal protein sources.

Extruded full-fat soybeans

Full-fat soybeans may be used in diets fed to pigs provided that they have been heat treated prior to feeding. The development of relatively small farm-size extruders makes home extrusion of soybeans and subsequent use of extruded full-fat soybeans an option for swine producers. Extruded full-fat soybean meal is an excellent feed ingredient that may be used in diets fed to all categories of pigs.

The concentration of energy in full-fat soybeans is greater than in soybean meal because of the greater concentration of oil in full-fat soybeans (Woodworth et al., 2001). Diets containing full-fat soybeans, therefore, usually contain more energy than if soybean meal is used. The digestibility of amino acids in full-fat soybeans is also greater than in soybean meal (Cervantes-Pahm and Stein, 2008), which may be a result of the greater concentration of oil in full-fat soybeans than in soybean meal because it has been demonstrated, that the inclusion of soybean oil in diets fed to swine results in improved digestibility of amino acids (Cervantes-Pahm and Stein, 2008). It is believed that this increase in amino acid digestibility is a result of a reduced rate of passage for diets containing soybean oil compared with diets containing no soybean oil (Cervantes-Pahm and Stein, 2008). It is, therefore, possible that diets containing extruded full-fat soybeans also have a reduced passage rate through the intestinal tract of pigs compared with diets containing soybean meal, but this hypothesis has not been tested.

Extruded full-fat soybeans are often included in diets fed to nursery pigs and weanling pigs tolerate extruded full-fat soybeans well (Qiao et al., 2003; Zarkadas and Wiseman, 2004). Extruded full-fat soybeans may also replace soybean meal in diets fed to growing-finishing pigs without any negative impact on pig performance (Leszczynski et al., 1992), but belly firmness may be reduced if full fat soybeans are used during the finishing period. However, if pigs are offered a diet containing no full-fat soybeans during the final 3 weeks prior to slaughter, belly quality is not impaired by feeding full-fat soybeans (Leszczynski et al., 1992). Extruded full-fat soybeans may also be included in diets fed to sows and can potentially replace all soybean meal in gestating and lactating sows.

CONCLUSIONS

New varieties of soybeans as well as new technologies for post harvest processing of soybeans and soybean meal has resulted in the development of several new soybean products for the feed industry. High protein soybean meal that contains 56% crude protein and 3.5% lysine is available and offers an opportunity for including less soybean meal in diets fed to swine without reducing the inclusion of digestible amino acids. High protein soybean meal also contains more digestible and metabolizable energy than conventional soybean meal. Soybean meal produced from low oligosaccharide soybeans contains more amino acids, but fewer oligosaccharides, than conventional soybean meal. Low oligosaccharide soybean meal may, therefore, be better tolerated by young animals than conventional soybean meal, but experiments to verify this hypothesis have not yet been conducted.

Post harvest processing of soybean meal using fermentation or enzymes removes the antigens along with oligosaccharides and sugars in soybean meal. This results in high protein soybean meal without antigenic properties, which is believed to be better tolerated by young pigs than conventional soybean meal. These new sources of soybean meal may, therefore, be used in diets fed to young pigs, and thus, reduce the need for using animal proteins in these diets. The development of on-farm extruders that can inactivate trypsin inhibitors in soybean meal has made it possible to use home-grown soybeans in the feeding of swine. Extruded full-fat soybeans may be used for all categories of swine and will often result in improved performance compared with diets containing soybean meal. However, because of the risk of reducing belly firmness, it is recommended that full-fat soybeans are removed from the diets during the final 3 weeks prior to slaughter.

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Table 1. Composition of soybeans and soybean meal (DM-basis)[1]

Item	Soybeans	Soybean meal
Dry matter, %	89.6	89.0
Crude protein, %	41.3	54.2
Acid hydrolyzed fat, %	18.6	4.4
Ash, %	5.5	7.5
Carbohydrates, %	34.6	33.9
Non-starch polysaccharides, %	20.2	14.1
Non-structural carbohydrates, %	14.4	19.8
Free sugars, %	0.8	-
Sucrose, %	4.8	6.6
Oligosaccharides, %	4.5	6.4
Raffinose, %	0.62	1.18
Stachyose, %	3.75	4.98
Verbascose, %	0.16	0.22
Uronic acid, %	3.4	3.7

[1]Adapted from Grieshop et al. (2003).

Table 2. Protein and amino acid concentration in conventional and high protein soybeans and soybean meal (%, as-is basis) [1]

Item	Conventional		High Protein	
	Soybeans	Soybean meal	Soybeans	Soybean meal
DM, %	93.43	89.10	94.91	89.20
CP, %	35.78	48.40	47.64	55.70
Indispensable AA, %				
Arg	3.00	3.62	3.83	4.30
His	0.98	1.30	1.24	1.47
Ile	1.64	2.30	2.02	2.56
Leu	2.76	3.81	3.43	4.31
Lys	2.35	3.20	2.81	3.51
Met	0.59	0.70	0.64	0.78
Phe	1.84	2.50	2.31	2.85
Thr	1.39	1.86	1.66	2.09
Trp	0.33	0.69	0.33	0.75
Val	1.77	2.45	2.16	2.74
Dispensable AA, %				
Ala	1.57	2.14	1.89	2.35
Asp	4.08	5.58	5.25	6.47
Cys	0.61	0.77	0.66	0.91
Glu	6.39	8.93	8.31	10.39
Gly	1.54	2.11	1.89	2.35
Pro	1.7	2.51	2.17	2.86
Ser	1.74	2.25	2.21	2.64
Tyr	1.33	1.79	1.63	1.98

[1] Data from Baker and Stein (2008) and from Cervantes-Pahm and Stein (2008).

Table 3. Standardized ileal digestibility (%) of protein and amino acids in conventional and high protein soybeans and soybean meal [1]

Item	Conventional		High Protein	
	Soybeans	**Soybean meal**	**Soybeans**	**Soybean meal**
CP, %	92.1	87.3	94.1	88.3
Indispensable AA, %				
Arg	96.7	94.7	99.1	94.7
His	91.6	90.6	93.3	89.7
Ile	90.2	88.4	93.1	88.3
Leu	89.7	88.1	92.5	88.3
Lys	92.5	90.0	93.0	90.1
Met	92.2	89.3	94.0	88.6
Phe	90.7	88.6	93.7	88.7
Thr	86.4	85.5	87.6	85.3
Trp	89.4	93.8	90.1	89.6
Val	89.0	86.8	91.7	86.8
Dispensable AA, %				
Ala	91.1	85.0	92.7	84.9
Asp	89.7	86.0	91.0	86.1
Cys	85.0	83.0	84.9	82.9
Glu	90.7	87.7	91.0	87.5
Gly	89.2	88.2	93.9	88.1
Pro	153.7	114.4	153.6	117.1
Ser	88.6	89.0	91.1	89.2
Tyr	90.9	88.7	93.6	88.3

[1] Data from Baker and Stein (2008) and from Cervantes-Pahm and Stein (2008).

Table 4. Analyzed nutrient composition of soybean meal, HP 300, and PepSoyGen (%, as-is basis)[1]

Item	Soybean meal	HP 300	PepSoyGen
DM	89.32	91.48	91.33
CP	45.07	54.40	53.74
Ether extract	1.07	1.13	0.80
Crude fiber	2.78	3.75	3.31
Ca	0.26	0.35	0.29
P	0.67	0.74	0.82
Glucose	0	0.49	0.36
Sucrose	7.81	0	0
Fructose	0.63	1.11	0.70
Stachyose	5.17	0.71	0
Raffinose	1.08	0.16	0
Indispensable AA			
Arg	3.06	3.75	3.50
His	1.13	1.35	1.30
Ile	1.89	2.31	2.48
Leu	3.37	3.98	4.09
Lys	2.77	3.06	3.11
Met	0.63	0.71	0.76
Phe	2.23	2.74	2.71
Thr	1.71	2.02	1.98
Trp	0.62	0.69	0.67
Val	1.96	2.40	2.69
Dispensable AA, %			
Ala	1.86	2.25	2.29
Asp	4.80	5.71	5.67
Cys	0.67	0.76	0.77
Glu	7.48	8.75	8.56
Gly	1.77	2.26	2.23
Pro	2.08	2.46	2.45
Ser	1.97	2.35	2.24
Tyr	1.67	2.03	1.97

[1] Data from Pahm (2008).

Table 5. Standardized ileal digestibility (%) by weanling pigs of crude protein and amino acids in soybean meal, HP 300, and PepSoyGen [1, 2]

Item	Soybean meal	HP 300	PepSoyGen
CP	80.3	92.2	82.2
Indispensable AA			
Arg	90.9	98.2	93.5
His	84.0	88.9	84.4
Ile	82.9	89.8	85.8
Leu	82.0	89.3	85.4
Lys	79.2	88.3	77.2
Met	85.5	92.2	88.3
Phe	84.1	91.9	87.2
Thr	77.4	85.8	78.5
Trp	84.8	87.5	83.5
Val	81.9	89.5	84.3
Dispensable AA			
Ala	77.0	88.7	81.0
Asp	79.5	88.3	81.7
Cys	73.4	85.2	69.7
Glu	81.1	93.7	84.2
Gly	65.0	94.9	74.6
Pro	120.7	149.4	132.5
Ser	82.5	89.4	82.2
Tyr	86.1	92.1	87.7

[1] Data from Pahm (2008).

[2] Data are means of seven observations per treatment.