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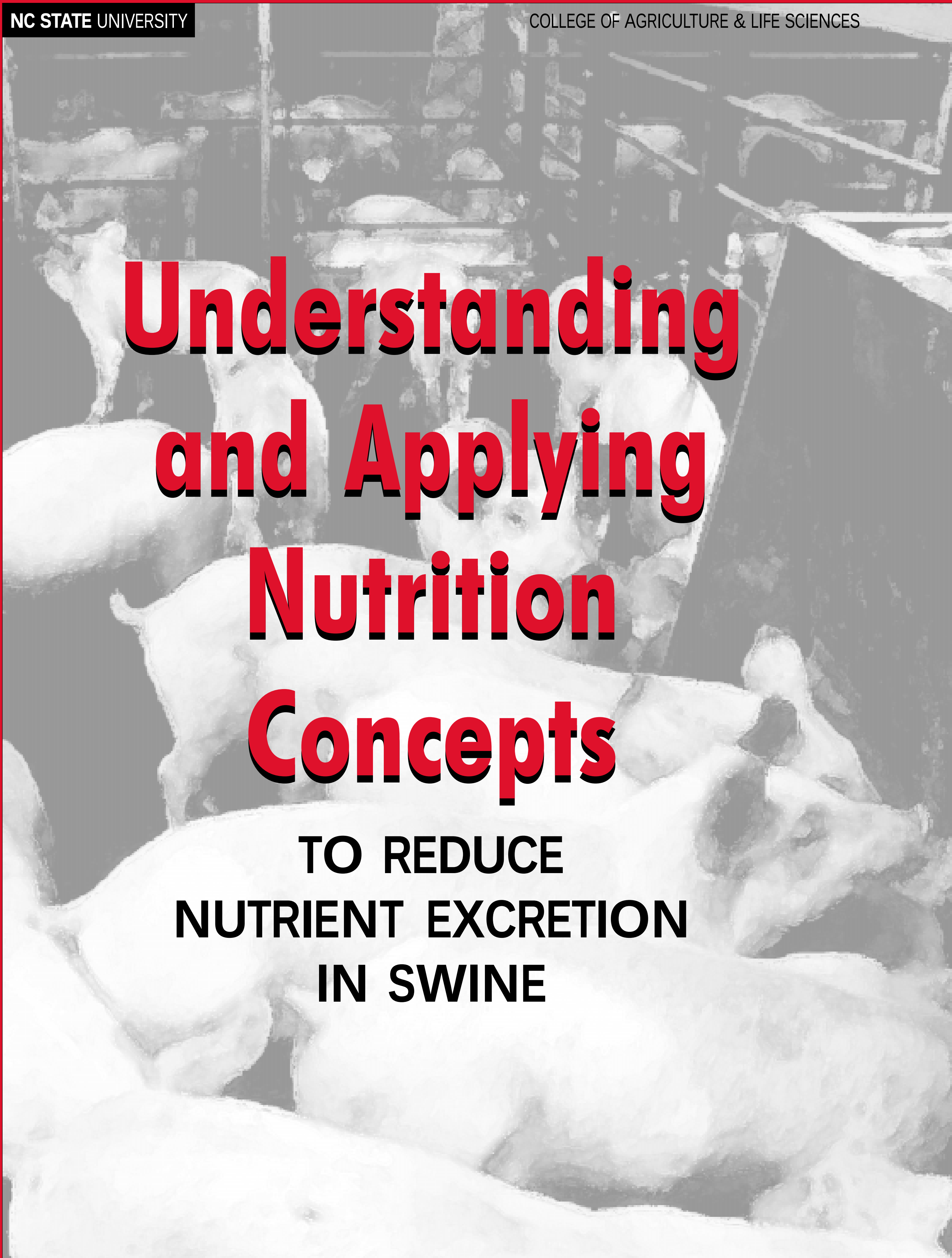
COLLEGE OF AGRICULTURE & LIFE SCIENCES



Understanding and Applying Nutrition Concepts

TO REDUCE NUTRIENT EXCRETION IN SWINE

Swine production in the United States has changed dramatically over the last 50 years. Specifically, the industry has shifted toward a highly specialized systems approach, which has resulted in the concentration of production in certain areas of the country. The disposal of animal waste becomes a challenge in the intensive production of swine because the amount and nutrient composition of the manure may exceed the capacity of the land to accept it as a fertilizer. Therefore, alternative methods of animal manure disposal are needed urgently.

Growing-finishing pigs are responsible for the bulk of nutrient excretion in manure (Table 1). On average, each finishing pig produces approximately 1.2 gallons of manure (not including flush water or water wastage) every day. This adds up to 21 pounds of nitrogen and approximately 15 pounds of phosphorus per pig per year. To reduce the environmental impact of pig production, methods may be focused on finding different techniques and strategies for processing manure, reducing odor, or reducing the excretion of nutrients in manure. Nutrient excretion is a result of the inefficiencies associated with digestion and metabolism. Typically only 20 percent to 50 percent of the nitrogen and 20 percent to 60 percent of the phosphorus consumed are retained in the body (Table 2); therefore, 50 percent to 80 percent of the nitrogen and 40 percent to 80 percent of the phosphorus consumed are excreted into the environment. This illustrates the potential for using dietary strategies to reduce nutrient excretion. In addition, by minimizing the amount of nutrients, particularly protein, that enters the large intestine without being digested, odor formation by microorganisms in the large intestine can be reduced. Thus, in general, methods that reduce nutrient excretion often reduce odor emission.

This paper will discuss general strategies to reduce nutrient excretion and describe specific methods to reduce nitrogen, phosphorus, and micro-mineral excretion. They include feed wastage, separate-sex and phase feeding, and formulating diets based on nutrient availability. They also include the use of phytase, low-phytate corn, and low-protein diets.

General nutritional strategies to reduce nutrient excretion

Feed efficiency

Improving feed efficiency is the most logical approach to reduce nutrient excretion. Improving feed efficiency by 0.1 points (*i.e.*, lowering feed per gain from 3 to 2.9) will result in a 3.3 percent reduction in nutrient excretion (assuming similar

Table 1. Amounts of nitrogen output for different classes of swine, calculated for a 100-sow equivalent (89 productive sows)[1]

Class	Nitrogen Output			
	Per Pig (g/d)	Per Space (kg/year)	% of Total	N Output/N Intake (%)
Sows				
Replacement Gilts	51	186	1.7	69
Weaned Sows	42	103	0.9	73
Gestation	40	954	8.7	77
Lactation	79	459	4.2	57
Piglets				
Suckling (27 d)	1	54	0.5	14
Post-weaning (to 25 kg)	11	907	8.2	47
Growing-Finishing Pigs				
25 to 105 kg	38	8,360	75.8	67
Total		***11,023***	***100***	***65***

[1] Adapted from Dourmad *et al.* (1992).

Table 2. Digestion and retention of nitrogen, phosphorus, copper, and zinc by different classes of swine[1]

Mineral	Nursery	Finishing	Gestating	Lactating
Nitrogen				
Digested, %	75 to 88	75 to 88	88	—
Retained, %	40 to 50	30 to 50	35 to 45	20 to 40
Phosphorus				
Digested, %	20 to 70	20 to 50	30 to 45	10 to 35
Retained, %	20 to 60	20 to 45	20 to 45	20
Zinc				
Digested, %	20 to 45	10 to 20	—	—
Copper				
Digested, %	18 to 25	10 to 20	—	—

[1]Adapted from Kornegay and Harper (1997).

growth and nutrient retention). Coffey (1996) stated that feed efficiency for growing-finishing pigs (from 50 pounds to 250 pounds) has improved from 4 to less than 2.85 in top-producing herds over the past 20 years. This change can be attributed largely to improvements in genetics and increased knowledge of nutrition. The deposition of lean tissue is more efficient than fat deposition. Therefore, selection for lean will result in improved feed efficiency. Using the numbers mentioned earlier, nutrient excretion can be reduced by more than 35 percent due to improving feed efficiency over time. This probably overestimates the impact that the improvement in feed efficiency had on nutrient excretion because nutrient density of the diets also has increased over time. Pelleting of feeds has the potential to improve feed efficiency and reduce nutrient excretion. Wondra *et al.* (1995) reported that pelleting decreased dry matter and nitrogen excretion in the feces by 23 and 22 percent, respectively. Considering that approximately 20 percent to 25 percent of the nitrogen in waste is excreted in the feces (Figure 1), the overall reduction in nitrogen excretion using pelleted diets is about 5 percent. Feed efficiency was improved by 6.6 percent in that study. Summarizing eight trials on pelleting diets for swine, Hancock *et al.* (1996) concluded that pelleting improved average daily gain by 6 percent and feed efficiency by 6 to 7 percent.

Feed wastage

Proper feeder management may be an easy way to reduce feed wastage and therefore improve efficiency of feed utilization. First, the type of feeder can affect feed wastage. For example, Ian Taylor and Stan Curtis at the University of Illinois studied 11 self-feeders for pigs that weighed 50 to 125 pounds. They measured how much feed fell on and through the floor and found that feed wastage ranged from 2.1 to 7.7 percent. Researchers in several countries have estimated feed wastage and have quoted values of 4 percent in the United States (with a range from 2 to 12 percent), 6 percent in Great Britain (with a range of 1.5 to 20 percent), and 3 to 5 percent in Denmark. Reducing feed wastage by 2 percent can save $0.84 per pig marketed (assuming a feed efficiency of 3 and a feed cost of $0.07 per pound). In addition, a 2 percent reduction in feed wastage can lower the nitrogen and phosphorus in manure by approximately 3 percent (based on a nitrogen and phosphorus retention of 35 percent). For proper feeder adjustment, the rule of thumb is that about 50 percent of the bottom of the trough needs to be covered with feed and the rest needs to be visible.

Matching nutrient requirements

Animals require fewer nutrients as they grow heavier due to changes in the maintenance requirement and the composition of growth (less lean and more fat). In addition, animals consume more feed as they grow heavier; therefore, the nutrient composition of their diet can be decreased as they gain weight. For example, according to the National Research Council (NRC, 1998), a 140-pound pig requires 19.7 grams of total lysine compared to a 220-pound pig, which requires 18.5 grams of lysine. Assuming a feed intake of 5.7 pounds per day and 6.8 pounds per day for the 140- and 220-pound pigs, respectively, the lysine requirements would be 0.75 percent for the 140-pound pig and 0.6 percent for the 220-pound pig. Phase feeding matches specific diets to the growth stage of the pig and reduces the time pigs are fed an over- or undersupply of nutrients. Van der Peet-Schwering *et al.* (1996) reported that multi-phase feeding reduced urinary nitrogen excretion by 14.7 percent and that ammonia emission was reduced by 16.8 percent. Multi-phase feeding was achieved by mixing a diet high in nitrogen with one low in nitrogen in decreasing proportions on a weekly basis and was compared with a two-phase feeding system. Koch (1990) estimated based on theoretical calculations that nitrogen and phosphorus excretion could be reduced by 13 percent by going from one feed for the grower-finisher period to two feeds, whereas Lenis (1989) estimated a 6 percent reduction in nitrogen excretion. Phase feeding will reduce the diet cost-per-pig and is a cost-effective method of reducing nitrogen excretion. The cost benefits of phase feeding were reported in an article in *Pork 98* (Bell, 1998) as shown in Table 3. Costs used in this example were $2.24 per bushel for corn and $240 per ton for soybean meal (44 percent crude protein). Savings were based on the assumption that pig performance would be equal for all phase feeding programs. Similarly, separate-sex feeding will match nutrient concentrations to the requirement of the pig more closely and is expected to result in a reduction in nutrient excretion and savings in diet costs.

Feed manufacturing

Knowledge of the content and availability of nutrients in feedstuffs and accuracy in feed manufacturing would give producers a chance to decrease the excretion of excess nutrients (or, alternatively, avoid deficiencies). Spears (1996) summarized analysis results from 26 sow feed samples and 17 finishing feed samples (Table 4). One sample was taken from each of 43 farms and analyzed by the North Carolina Feed Testing Laboratory. The results indicate that there is substantial variation in the mineral concentrations of different feeds. The levels of minerals exceeded

Table 3. Savings in feed costs with phase feeding[1]

Number of Phases	Diet Cost/Pig	Savings Over 2-Phase Program	Increase in Savings Per Additional Diet
2	$42.44	—	—
3	$41.41	$1.14	$1.14
4	$41.01	$1.54	$0.40
5	$40.67	$1.88	$0.34
6	$40.43	$2.12	$0.24
9	$40.10	$2.45	$0.11
12	$39.90	$2.65	$0.06

[1] From Bell (1998).

Table 4. Concentrations of selected minerals in sow and grower-finisher feeds[1]

Mineral	Sow Diets			Finisher Diets		
	Requirement	Range	Median[2]	Requirement	Range	Median[2]
Calcium, %	0.75	0.62 - 2.01	1.21	0.50	0.57 - 1.38	0.96
Phosphorus, %	0.60	0.45 - 1.17	0.84	0.40	0.45 - 0.78	0.62
Copper, ppm	5	12 - 222	22	3	9 - 281	20
Zinc, ppm	50	79 - 497	167	50	103 - 205	149

[1] Adapted from Spears (1996).

[2] The median value indicates that 50 percent of the samples were below this value and 50 percent of the samples were above.

the requirements suggested by the NRC. The difference is likely due, in part, to variation in requirement estimates among nutritionists, but is also probably related to the lack of analyzed nutrient profiles of the ingredients used to formulate the feed and to errors in mixing. Adding excess nutrients to diets to account for variability in composition and accuracy in mixing can be used to avoid nutrient deficiencies, but it also will increase nutrient excretion and diet cost.

Methods to reduce nitrogen excretion and ammonia emission

As stated previously, pigs retain a relatively low percentage of the nitrogen they consume. Losses associated with nitrogen metabolism can be seen in Figure 1 and can be studied in detail using metabolism crates (Figure 2). Most of the nitrogen entering the pig's body is in the form of protein and amino acids. Digestion of protein to amino acids is initiated in the stomach by the combined action of hydrochloric acid and pepsin and is completed in the small intestine by proteases such as trypsin and chymotrypsin. These enzymes are proteins themselves and will contribute to the fecal excretion of nitrogen. In addition, other secretions from the intestine and sloughed-off cells are part of the nitrogen excretion in the feces and together are referred to as endogenous secretions. Part of the endogenous secretions are reabsorbed, but approximately 25 percent are passed into the large intestine (Souffrant *et al.*, 1993). Feeding tables typically list the amino acid digestibility values for ingredients as apparent ileal digestible values. These values take into account the losses from endogenous secretions because the digestibility calculations are based on the amount of amino acids at the end of the ileum (small intestine) compared to the intake of amino acids.

Therefore, selecting ingredients with a highly digestible amino acid content will reduce the fecal loss of nitrogen (Figure 1). The Federation Europeenne des Fabricants d'Adjuvants pour la Nutrition Animale (1992) estimated that nutrient excretion in waste could be reduced by approximately 5 percent by selecting highly digestible ingredients. However, cost effectiveness, ingredient storage capacity, and quality control become issues in adapting this method.

Figure 2. Metabolism crates are used to study nutrient digestion, metabolism, and excretion.

Front and side view of a swine metabolism crate.

The metabolism crates used at North Carolina State University are designed to hold pigs weighing between 50 and 350 pounds. The sides of the crates can be adjusted to make sure the pig cannot turn around. This is necessary to ensure that feces and urine are deposited in one area, facilitating complete collection.

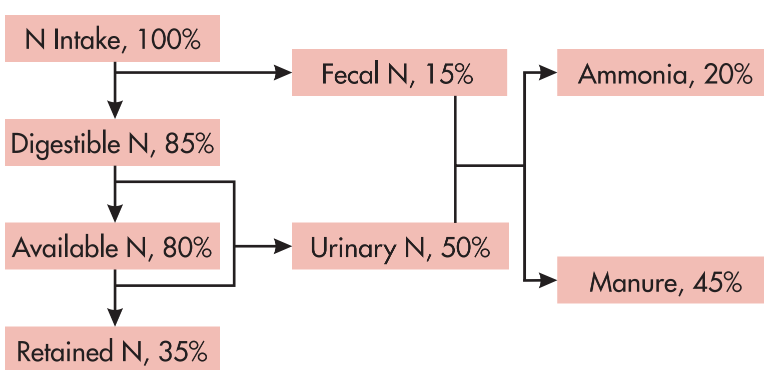


Figure 1. Nitrogen flow in swine

Inside view of a metabolism crate with feeder in front.

The pig stands on a slotted floor that has been coated with plastic. Underneath the floor is a screen that will collect all the fecal material voided by the pig. Under the screen is a stainless steel tray that drains into the center and collects all the urine produced during the day.

Knowing the amount and the nutrient composition of the feed given each day, we can calculate total nutrient intake. We also can measure the amount of feces and urine produced per day and determine the chemical composition of each. From these data, we can calculate the digestibility of the feed and the efficiency with which it is metabolized. Then we can estimate the total nutrient excretion in feces and urine and study several nutritional strategies aimed at minimizing this excretion.

Low-protein diets

Following digestion of proteins, amino acids are absorbed and used for muscle protein synthesis and other physiological functions. The ideal protein concept, introduced by the Agricultural Research Council (ARC, 1981), proposes that ideal protein consists of amino acids in exactly the right proportions for maintenance and lean tissue growth. According to this concept, each amino acid is equally limiting and, per definition, excretion of nitrogen is minimized. Requirements of all essential amino acids are expressed as a percentage of lysine (the first amino acid that would limit pig growth in practical swine diets). From a practical standpoint, the ideal protein concept allows for a quick calculation of amino acid requirements as long as the lysine requirement of the pig is defined. However, the exact ideal protein may be variable, depending on the physiological state of the animal. This may explain the different ideal protein or amino acid patterns that have been proposed. Baker (1996) calculated ideal amino acid patterns for pigs in different weight categories (Table 5). Others (Fuller *et al.* 1989) studied optimum amino acid patterns for maintenance and growth. Because the maintenance component increases relative to protein deposition, the combined ideal pattern of amino acids will change with increasing body weight. Similarly, the amino acid requirements for swine as calculated in the new NRC publication (1998) are based on different patterns for maintenance and growth.

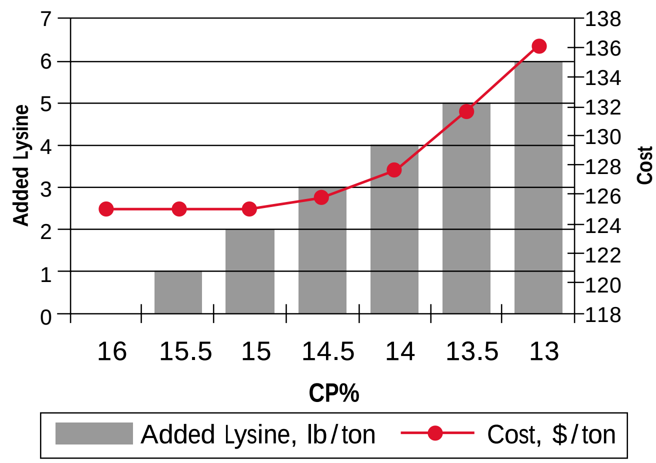
Table 5. Ileal true digestible amino acid patterns for pigs in three different weight classes[1]

	Ideal Pattern, % of Lysine		
Amino Acid	10 to 45 lbs	45 to 110 lbs	110 to 240 lbs
Lysine	100	100	100
Threonine	65	67	70
Tryptophan	17	18	19
Methionine + Cystine	60	62	65
Isoleucine	60	60	60
Valine	68	68	68
Leucine	100	100	100
Phenylalanine + Tyrosine	95	95	95
Arginine	42	36	30
Histidine	32	32	32

[1]Adapted from Baker (1996).

Chung and Baker (1991) used this concept to the extreme and fed 20-pound pigs either a corn-soybean meal-whey diet or a purified diet containing corn starch, lactose, and sucrose as the carbohydrate sources and individual amino acids at the ideal ratios as the only nitrogen source. The results demonstrated that equal performance could be obtained with the low-nitrogen, purified diets (1.1 pounds per day on average for the 14-day feeding period). However, nitrogen excretion was substantially different. Pigs fed the corn-soybean meal-whey diet excreted 44 percent of nitrogen in feces and urine, compared to 32 percent for pigs fed the purified diet. Therefore, by applying the ideal protein concept, nitrogen excretion could be reduced by up to 30 percent. However, under practical conditions, least-cost formulation of diets would allow only for a small reduction in the protein content of the diet. The cost associated with reducing the crude protein content of a corn-soybean meal diet is shown in Figure 3. These calculations were made using a 16 percent crude protein diet without added synthetic amino acids (containing 0.82 percent total lysine), and minimum amino acid levels were set using the ratios presented in Table 5. Although only added lysine per ton of feed is shown in this graph, other amino acids (threonine, methionine, and tryptophan) needed to be included to maintain the proper amino acid pattern. This occurred with the 14.5 percent crude protein diet, which resulted in an increase of $0.70 feed cost per ton compared to the 16 percent crude protein diet. The reduction in nitrogen excretion was not given a value in this example, but will become a factor of increasing importance in the future.

Figure 3. Cost or value of reducing crude protein (CP) in a corn-soybean meal diet*



* Relevant ingredient prices used were as follows: corn, $90/ton; dehulled soybean meal, $180/ton; Lysine-HCl, $2,400/ton; DL-Methionine, $2,700/ton, Threonine, $2.63/lb; and Tryptophan, $15.80/lb.

Nitrogen content of swine feeds can be reduced cost effectively by formulating diets based on amino acids, rather than protein. Based on the prices used in this example, the nitrogen content of the diet can be reduced by 0.16 percent (1 percent crude protein) without increasing diet cost. Kerr (1995) concluded from a summary of 28 experiments that for each 1 percent reduction in crude protein, nitrogen excretion was reduced by 8.4 percent. In addition to a reduction in nitrogen excretion, the feeding of low-protein diets also can affect ammonia levels in the air and odor. Latimier (1993) reported a reduction of nitrogen in the air of approximately 15 percent by feeding low-protein diets (Table 6). Note that nitrogen excretion was reduced by 16 percent by lowering the protein content of grower diets and finisher diets by 1.6 percent (from 17.8 percent to 16.2 percent) and 1.9 percent (from 15.4 percent to 13.5 percent), respectively.

Table 6. Effect of low-protein diets on nitrogen excretion and ammonia emission[1]

	Grower and Finisher Protein Level, %[2]	
Item	17.8% and 15.4%, resp.	16.2% and 13.5%, resp.
N Intake, lbs	2.43	2.17
N Retention, lbs	0.79	0.79
N excretion		
Total excretion, lbs	1.64	1.38
N in manure, lbs	1.20	1.00
N in air, lbs	0.44	0.38

[1] Adapted from Latimier, 1993.
[2] The grower and finisher periods covered the weight ranges of 68 to 139 lbs. and 139 to 223 lbs., respectively.

Figure 4. The Swine Malodor Emission Laboratory at North Carolina State University

Odor chamber **Chamber, inside** **FTIR equipment**

Dr. Theo van Kempen has initiated a research program on odor control in swine through nutritional means at North Carolina State University. He has developed the Swine Malodor Emission Laboratory (SMEL), which contains two chambers for housing pigs. In each of these chambers, the amount and composition of the air going into and coming out of the chamber is measured. Thus, odor compounds can be identified and quantified through a technique called Fourier Transform Infrared Spectroscopy (FTIR), which measures these compounds based on their light-absorption characteristics. Studies are currently in progress to investigate nutritional effects on odor emission.

On average from this study, nitrogen excretion was reduced by 9 percent and ammonia emission by 8.6 percent per 1 percent reduction in crude protein. Hobbs *et al.* (1996) observed a reduction in odor compounds when pigs were fed diets low in protein. A comparison between diets high in protein (20.8 percent crude protein for the grower and 18.9 percent crude protein for the finisher; note that these levels of crude protein are relatively high compared to practical swine diets in the United States) and diets low in protein (16.1 percent crude protein for the grower and 13.8 percent crude protein for the finisher) revealed that the concentration of 5 out of 10 odor compounds measured were lower in the low-crude protein diets during the grower period. During the finisher period, 9 out of 10 odorous compounds were lower for the low-crude protein diets. Because of the importance of odor in the perception of swine production by the public, this area of research warrants further investigation and is being studied at North Carolina State University (Figure 4).

Methods to reduce phosphorus excretion

Most of the phosphorus in an animal is found in its bone. However, phosphorus also plays an important role in a number of metabolic functions. Feedstuffs derived from grains and plant protein contain significant amounts of phosphorus. However, the phosphorus in plants is largely bound as phytate, which is unavailable to the pig. The bioavailability of phosphorus in feedstuffs of vegetable origin ranges from 14 percent to 50 percent (NRC, 1998). Because most of the phosphorus in these feedstuffs will be excreted, formulation of diets based on the available phosphorus content and selection of ingredients with a high phosphorus availability can lead to a reduction in phosphorus excretion. Cromwell (1990) calculated total and available phosphorus levels in diets formulated to contain 0.5 percent total phosphorus using different ingredients (Table 7). The corn-soybean meal diet contained 0.23 percent available phosphorus, which was set as the requirement (NRC, 1998).

When wheat was used as the grain source, available phosphorus was greater than the requirement. In that case, phosphorus excretion would have been increased because available phosphorus exceeded what was needed. From extrapolations from the research of O'Quinn *et al.* (1997), it was calculated that for each 0.05 percent absolute reduction in available phosphorus in the diet, excretion of phosphorus was reduced by approximately 8 percent. For both a canola meal diet and a diet with wheat middlings, the level of available phosphorus was calculated to be below the requirement. This example illustrates that excesses and deficiencies of phosphorus can be overcome by formulating based on available phosphorus. However, an accurate knowledge of the available phosphorus requirement for all classes of pigs is needed.

Digestibility of phosphorus in feedstuffs of vegetable origin can be improved substantially by the use of phytase. Phytase is an enzyme that can break down the phytic acid molecule, releasing phosphorus and making it available to the pig. Kornegay (1996) estimated that phosphorus excretion in the feces could be reduced by 25 to 50 percent with the use of 200 to 1,000 units of phytase. In a summary of the available literature on phytase supplementation (Hoppe and Schwartz, 1993, as cited by Kornegay, 1996), it was suggested that 432 units of phytase per kilogram were equivalent to 0.1 percent of phosphorus. The economic value of using phytase when following the common recommendation that 500 units per kilogram of phytase is equal to 0.1 percent of phosphorus can be calculated (Table 8). The cost of phytase was $1.36 per pound for a phytase premix containing 600 units phytase per gram; the cost for dicalcium phosphate (18.5 percent phosphorus) was $245 per ton, and the cost of other ingredients was the same as listed in Figure 3. The calculation is based purely on least-cost diet formulation and does not take into account the value of reduced phosphorus excretion due to improved phosphorus digestibility with the addition of phytase. In addition, any potential value of phytase on amino acid or energy digestibility was not taken into account.

Table 7. Available phosphorus levels in diets formulated to contain 0.5 percent total phosphorus[1]

Diet	Added Dical. P, %	Total P, %	Available P, %
Corn-Soybean Meal	0.96	0.50	0.23
Wheat-Soybean Meal	0.57	0.50	0.28
Corn-Canola Meal	0.09	0.50	0.10
Corn-Soybean Meal-Wheat Midds	0.68	0.50	0.20
Growing Pig Requirement (NRC)		0.50	0.23

[1]Adapted from Cromwell (1990).

Table 8. Estimated cost of phytase supplementation using least-cost diet formulation

Level of Phytase Added	Dicalcium phosphate removed (lb/ton)	Diet cost above a standard corn-soybean meal diet
500 U per kg	10.9	$1.23
250 U per kg*	10.9	$0.14

*The level of 250 U of phytase per kg is below the recommended inclusion level and may not liberate sufficient P to maintain pig performance.

Table 9. Bioavailability of regular and low-phytate corn in pigs

Start weight of pigs	Length of trial	Number of pigs used	Criteria of measurement	Availability of P in corn	Availability of P in LPC[1]	Standard used[2]	Reference
34 lb	40 days	35	Bone strength, Ash	22	77	MSP	Cromwell *et al.*, 1998
20 lb	35 days	50	Bone strength	10	64	MSP	Spencer *et al.*, 1998a
40 lb	34 days	40	Bone strength, Ash	22	79	MSP	Pierce and Cromwell, 1999a

[1]LPC is low-phytate corn.

[2]MSP is monosodium phosphate. The availability of P in MSP is set at 100%.

Table 10. Effects of regular and low-phytate corn on performance of growing pigs[1]

	Regular Corn				Low-Phytate Corn			
Total P, %	0.59	0.50	0.42	0.33	0.59	0.50	0.42	0.33
Available P, %	0.35	0.26	0.18	0.09	0.45	0.37	0.28	0.20
Daily Gain, lb.	1.78	1.76	1.62	1.36	1.75	1.71	1.73	1.70
Feed/Gain	2.37	2.37	2.44	2.79	2.39	2.54	2.38	2.35
Bone Strength	90	86	66	41	87	89	85	64
Bone Ash, %	50.6	50.6	48.7	45.2	51.0	50.9	50.4	46.9

[1]Each mean represents five pens of two pigs per pen. Initial and final pig weights were 50 and 112 lb., respectively, for the 37-day trial. Bone strength and bone ash are average values for the metacarpals and metatarsals.

Grain companies are developing corn varieties that contain less phytate-bound phosphorus and have identified the *lpa1* gene, which causes a large reduction in phytic acid production in corn seeds. Lines of hybrid corn containing this gene (low-phytate corn) have been tested in swine experiments to determine the availability of phosphorus. In addition, the effects of low-phytate corn on pig performance have been evaluated. Low-phytate corn contains approximately the same level of total phosphorus as regular corn (0.28 percent phosphorus in regular corn, NRC, 1998). The pig can use the bioavailable portion, which is only 14 percent of the phosphorus in regular corn—86 percent is excreted in the manure. The bioavailability of low-phytate corn, on the other hand, is much higher as determined in recent experiments (Table 9). On average, phosphorus in regular corn was 18 percent available, whereas phosphorus in low-phytate corn was 73 percent available.

Pierce *et al*. (1998a) evaluated the effect of replacing regular corn with low-phytate corn based on total phosphorus. The total phosphorus levels in the final diets ranged from 0.33 percent to 0.59 percent, and two of those levels were below the total phosphorus requirement of 0.5 percent suggested by the NRC (1998). However, as mentioned before, the amount of phosphorus available to the pig is higher for low-phytate corn, and therefore, there was more available phosphorus in the low-phytate corn diets (Table 10). The NRC (1998) lists an available phosphorus requirement for growing pigs of 0.23 percent, which means that the lowest phosphorus diet using low-phytate corn was only marginally deficient in phosphorus (it contained 0.2 percent available phosphorus).

In fact, the greater availability of phosphorus in low-phytate corn resulted in an improvement in daily gain of 25 percent compared to regular corn-fed pigs whose diets had the lowest level of phosphorus. Other studies have reported improved performance ranging from 8 to 23 percent (Pierce *et al.*, 1998b; Spencer *et al.*, 1998b). The magnitude of performance improvement likely would depend on the design of the trial, particularly the level of dietary phosphorus used and how it compared to the pigs' requirement. Because more phosphorus from the low-phytate corn is used by the pig, phosphorus excretion can be reduced by feeding low-phytate corn. Research has demonstrated that phosphorus excretion can be reduced from 13 to 50 percent (Pierce *et al.*, 1998a; Pierce and Cromwell, 1999b; Veum *et al.*, 1998). When diets were formulated based on available phosphorus (rather than total phosphorus) using low-phytate corn, phosphorus excretion was reduced by 35 to 40 percent (Pierce and Cromwell, 1999b). Collectively, these data show that total dietary phosphorus can be reduced by 0.1 percent when low-phytate corn is used and that phosphorus excretion can be reduced by approximately 40 percent.

An interesting question is what effect phytase would have in diets that contain low-phytate corn. There is still potential for phytase to improve phosphorus digestibility because other components of pig diets, such as soybean meal, contain significant amounts of phytate-bound phosphorus. Cromwell (1999) reported that phytase addition to diets with low-phytate corn decreased phosphorus excretion by 25 percent (Table 11). Using phytase and low-phytate corn diets reduced phosphorus excretion by 51 percent compared to control diets with regular corn and without phytase.

There is great potential for using low-phytate corn and phytase to reduce phosphorus excretion in swine. The feasibility of applying these technologies in practice depends on the cost of inclusion versus the economic benefits and the ability to preserve the identity of different types of corn.

Table 11. Effects of low-phytate corn and supplemental phytase on phosphorus excretion of pigs

	Regular Corn		Low-Phytate Corn	
	Control	With Phytase	Control	With Phytase
Total P, %	0.55	0.45	0.45	0.35
Available P, %	0.29	0.19	0.29	0.19
Bone Strength, kg	272	267	282	283
P Excretion, g/day	6.80	5.24	4.43	3.34
Reduction in P Excretion, %	—	23	35	51

Table 12. Excretion of zinc and copper by different classes of swine[1]

	Zinc		Copper	
Phase	Diet, ppm	Excretion (grams/day)	Diet, ppm	Excretion (grams/day)
Nursery				
Prestarter	2,000	0.65	240	0.084
Starter	125	0.08	240	0.186
Grower-Finisher	125	0.23	15	0.027
Sows				
Gestation	125	0.20	15	0.024
Lactation	125	0.54	15	0.065

[1]Calculated on a daily basis.

Table 13. Impact of nutritional strategies on nutrient excretion

Strategy Employed	Reduction in Nutrient Excretion
Pelleting	5% for N and P
Reducing Feed Waste	1.5% for all nutrients for every 1% reduction
Matching Nutrient Requirements (Phase feeding or separate sex feeding)	6 to 15% for all nutrients
Formulation on availability	10% for N and P
Low-protein diets	9% for N for every 1% reduction in dietary CP
Phytase	25 to 50% for P
Low-phytate corn	35 to 40% for P
Reducing micro-minerals	Up to 50%

Methods to reduce the excretion of micro-minerals

The excretion of the micro-minerals zinc and copper from each of the classes of swine is shown in Table 12. Zinc and copper retention was assumed to be 20 percent (Table 2), except when growth-promoting levels of zinc and copper were fed, in which case retention was set at 5 percent (NRC, 1998). The opportunity to reduce zinc and copper excretion by eliminating high zinc and copper feeding in the nursery phase is substantial. The practice of feeding approximately 20 times the zinc and copper requirement to nursery pigs is common to increase the pigs' growth performance. Therefore, lowering these growth-promoting levels to reduce excretion may reduce pig performance. A better understanding is needed regarding the growth-promoting effects of these minerals and the economics of eliminating high levels from nursery diets.

Even if growth-promoting levels of zinc and copper are eliminated, a further reduction of micro-minerals below levels that are commonly fed in the industry can reduce mineral excretion significantly. Creech *et al.* (1998) reduced the levels of copper, zinc, iron, and manganese from 25, 150, 180, and 60 parts per million (ppm), respectively, in the nursery (note that zinc and copper already were reduced from the growth-promoting level of 2,000 and 240 ppm, respectively, in these diets) and 15, 100, 100, and 40 ppm, respectively, in the grower-finisher to 5, 25, 25, and 10 ppm, respectively, in the low-mineral diet. No effects on growth performance were observed during the nursery and grower-finisher periods. However, concentrations of zinc and copper in the feces were reduced by 50 percent. Effects of long-term feeding of reduced-mineral diets on reproductive performance of pigs are being evaluated currently.

Summary

Several nutritional strategies are available to reduce nutrient excretion. A summary of the methods discussed in this paper and their impact on nutrient excretion is provided in Table 13.

The most cost-effective methods that appear to be relatively easy to implement are reducing feed wastage, separate-sex and phase feeding, and formulating diets based on nutrient availability. The use of phytase, low-phytate corn, and low-protein diets could reduce nitrogen and phosphorus excretion substantially, but are likely to add additional cost to the diet.

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Prepared by
Eric van Heugten and Theo van Kempen
Swine Nutrition Extension Specialists

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