Feeding and Management System to Reduce Environmental Pollution in Swine Production** - Review -

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ABSTRACT : In this manuscript, several effective feeding and management systems to reduce environmental pollution in swine production have been briefly introduced. It is logical that reducing the excretion of nutrients in manure should be the first step to reduce the environmental impact of pig production. it is evident that the excretion of nitrogen and phosphorus can be reduced when more digestible or available feedstuffs are used. Also, it is well known that proper feed processing can reduce anti nutritional factors (ANF) and improve nutrient digestibilities. Supplementation of effective feed additives can reduce excretion of nitrogen and phosphorus due to efficient feed utilization. These include enzymes (e.g., phytase), antibiotics, probiotics, organic acids and growth hormones (β-agonists and porcine somatotropin). One of the most effective ways to reduce pollutants from swine manure is to use synthetic amino acids in feed manufacturing. Many studies showed that reduction of 2 to 4% unit (U) of dietary protein with supplemental amino acid (AA) could dramatically reduce (15 to 20%) nitrogen excretion. Regarding feeding strategies, it has been recognized that phase feeding regimen could be used to reduce nitrogen and phosphorous excretion by feeding pigs in better agreement with age and physiological state. Feeding barrows and gilts separately, known as split sex feeding, can also decrease excretion of nitrogen and phosphorus. With the increasing concerns on the negative impact of animal production systems on the environment, animal nutritionists and producers should be aware that sustainability of animal agriculture is as important as high production performance. Therefore, some feeding and management strategies described in this manuscript will help to reduce environmental pollution in swine production. Proper combination of feeding regimen and environment-friendly diet formulation through nutritional approach will be more effective to reduce nutrient excretion in swine production system compared to single approach to do so. *(Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 3 : 432-444)*

Key Words : Synthetic Amino Acids, Feed Additives, Nutrients Excretion, Pigs, Phase Feeding, Low Pollutant Diets

INTRODUCTION

With the increasing concerns on the negative impact of livestock production systems on the environment, it is evitable that the animal industry should be environmentally sound to ensure its long-term sustainable growth. In the past, dietary adjustments to animal requirements were aimed at maximizing production performance without special concern for nutrient (especially protein and amino acids) oversupply and environmental pollution. However, the recent environmental constraints have forced animal nutritionists to figure nutrient feeding not only in terms of nutrients retained in animal but also in terms of nutrients excreted.

On the average, finishing pigs produce approximately 4.5 L of manure (excluding flush water or water wastage) per pig each day. This equals a total of 9.5 kg of nitrogen and approximately 6.8 kg of phosphorus per pig per year. Methods to reduce the environmental impact of pig production may be focused on different processing techniques of manure after its production. However, this is one of factors to make swine production cost high. Therefore, reducing the excretion of nutrients in manure should be the first step to reduce the environmental impact of pig production. A large part of the nitrogen losses are associated with inefficiencies of digestion and metabolism. The retention of nitrogen and phosphorus in the pig body as a percent of intake is relatively low. It has been recognized that typically only 20~50% of the nitrogen and 20~60% of the phosphorus consumed is retained in the body (table 1; Kornegay and Harper, 1997). This illustrates the potential for reducing nutrient excretion through nutritional means.

Of nutrients excreted from animals, nitrogen and phosphorus are considered as main contributors to impact negatively on our soil and water environment. The amount of nitrogen and phosphorus that is excreted by pigs is affected by three main factors : (1) the amount of dietary nitrogen (protein) and phosphorus that is consumed, (2) the efficiency with which they are utilized by the animal for growth and

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other functions, and (3) the amount of endogenous secretions. Generally, little can be done to influence the amount of endogenous losses. Thus, in order to reduce the amount of nitrogen and phosphorus excreted by pigs, the amount that is consumed must be decreased, the efficiency of utilization of the dietary nitrogen and phosphorus must be increased, or both must occur.

Several nutritional strategies have been considered to be possible for reducing nutrients excreted. Therefore, this manuscript will briefly introduce some possible nutritional ways to reduce environmental pollution from swine production, with the aim of hoping that swine industry could be sustainable in the 21th century.

NUTRITIONAL APPROACH TO ENHANCE NUTRIENT AVAILABILITY

Choice of high available ingredients

To improve nutrient availability, it is very important to take the digestibility of nutrients in consideration when formulating diets. It is evident that the excretion of nitrogen and phosphorus can be reduced when more digestible or available feedstuffs is used. Also, to provide dietary nitrogen or phosphorus in accordance with the animals' need, adequate knowledge about the digestibility of amino acids or phosphorus in feedstuffs is required. Ileal digestibility would be more appropriate.

New sources of highly digestible feedstuffs are being developed by crop breeders, either using classical breeding techniques or through genetic modification of crops. Examples of such products are low-phytate corn and low-stacchyose soy. Corn is major feed ingredient in swine diets, but the bioavailability of phosphorus in corn is less than 15% (Cromwell, 1992; NRC, 1998). Corn-based diets require supplemental phosphorus from an inorganic source such as dicalcium phosphate to meet the available phosphorus needs of the pigs. Due to the high level of unavailable phosphorus in these diets, a large portion of dietary phosphorus is excreted. It has been known that the average lowered phytate levels in new corn varieties are 65 to 75% of the phosphorus in the corn to be available to the pigs. Thus, it is logical that use of low-phytate corn to diet can induce substantial reduction of phosphorus excretion when diets are formulated on an available phosphorus basis (Pierce et al., 1998). Recently, Spencer et al. (2000) compared phosphorus bioavailability and digestibility of normal and genetically modified low-phytate corn for weaned and growing pigs. They concluded that low-phytate corn contains at least five times as much available phosphorus as normal corn and the use of low-phytate corn reduced the amount of phosphorus by 37% and increased the nitrogen:phosphorus ratio in the manure compared to use of normal corn (table 2).

Proper feed processing

It is recognized that the digestibility could be improved through technological treatments of the feeds. For each 1% improvement in digestibility, nitrogen waste produced per kg of meat produced decreases by 1.4% (van Kempen, 2000). Examples of technological treatments include particle size reduction (grinding and roller milling), pelleting and expanding. Fine grinding and pelleting are effective in improving feed utilization and decreasing dry matter, nitrogen and phosphorus excretion. By reducing the particle size the surface area of the grain particles is increased allowing for greater interaction with digestive enzymes. Wondra et al. (1995) demonstrated that a uniform particle size of approximately 400 microns leads to a better nutrient digestibility than coarsely ground material (although ulcers may increase with fine particle size). Table 3 shows that regardless of mill types, reduction of particle size could reduce fecal excretion of dry matter and nitrogen by approximately 20% and 30%, respectively compared to coarse ground material. For practical purposes, Kansas State University (KSU) recommended a particle size of 700 microns (Goodband et al., 1998).

Vanschoubroek et al. (1971) calculated the effect of pelleting on performance based on a literature review; not only did animals prefer pelleted feed over mash feed, but feed efficiency was improved by 8.5% (for a large portion due to a reduction in feed waste),

Table 1. Digestion and retention of nitrogen and phosphorus by different classes of pigs (%)

Nutrients	Nursery	Finishing	Gestating	Lactating
Nitrogen				
Digested	75~88	75~88	88	-
Retained	40~50	30~50	35~45	20~40
Phosphorus				
Digested	20~70	20~50	30~45	10~35
Retained	20~60	20~45	20~45	20

(Kornegay and Harper, 1997)

Table 2. Digestibility and retention of nutrients of low-phytate and normal corn diets fed to 20 kg barrows[a]

Item	Low-phytate corn		Normal corn		SEM	p-value
Added P, %	0.2	0	0.2	0		
P digestibility, %	54.80	48.38	45.99	16.07	3.252	<0.01[b]
N digestibility, %	87.65	86.33	85.54	86.75	1.045	0.49
Energy digestibility, %	90.76	89.76	89.58	90.27	0.591	0.19
Ca digestibility, %	51.62	49.70	44.87	38.75	2.782	<0.01[c]
P retention, %	37.30	45.71	39.75	12.53	3.265	<0.01[b]
N retention, %	71.25	68.49	64.06	64.52	3.470	0.54
P excretion, g	13.17	8.25	13.21	11.06	0.643	<0.05[b]
N excretion, g	32.29	33.32	38.24	37.54	3.783	0.66
N:P of excreta	2.43	4.08	2.92	3.41	0.381	0.14

[a] Values are least squares means for a 5-d total collection period with five 20 kg barrows per treatment.
[b] Corn×phosphorus effect. [c] Main effect of corn hybrid. (Spencer et al., 2000)

and protein digestibility improved by 3.7%. Expanders and extruders are used mainly to provide flexibility in ingredient selection and to improve pellet quality rather than to improve nutrient digestion. Due to the high temperature in these machines, their effect on digestibility depends strongly on the composition of the feed (and digestibility can actually decrease in some cases).

It is also well known that proper feed processing can reduce anti-nutritional factors (ANF). Most legume seeds, such as soybeans, contain different ANF, i.e. protease inhibitors, lectins, tannins, and amylase inhibitors. Digestibility and absorption of protein is compromised when these ANF are present. Thus, elimination of ANF from the feed and better processing conditions can improve nitrogen utilization in pigs which will reduce nitrogen excretion.

Use of feed additives

Supplementation of feed additives can also reduce excretion of nitrogen and phosphorus through the improvement of feed utilization. One of the most representative feed additives to reduce nutrient excretion from animal manure is enzyme. Enzymes are used to increase the nutrient availability in feedstuffs for animals. These enzymes may do any or all of the following : 1) supplement the host's endogenous enzyme production, 2) increase availability of nutrient in the feed, 3) improve digestibility of indigestible fiber material and 4) decrease anti- nutritional factors (ANF) present in feed ingredients (Scott, 1991).

The carbohydrate fraction of feed ingredients consist of starch, sugar and non-starch polysaccharides (NSP), soluble dietary fiber fraction, like cellulose, hemicellulose, pectins and oligosaccharides. These NSP are resistant to digestive enzymes but digestibility of these fibrous feeds can be improved by treatment with enzymes that are capable of hydrolyzing the NSP to monosaccharides. Xylanases and β-glucanases are enzymes that are used to degrade NSP present in cereals such as wheat and barley. The pig does not secrete these enzymes and does not have the capability to digest and use NSP, resulting in a loss of usable energy from the diet. Because these NSP can trap other nutrients, such as protein and minerals, they also increase mineral excretion. The addition of xylanase and/or β-glucanase to cereal-containing diets can improve digestibility and feed efficiency. Graham and Inborr (1993) reported a 9% improvement in the ileal digestibility of protein in a wheat/rye diet due to enzyme addition.

Proteases, as the name implies, are used to degrade proteins. The use of proteases in animal feeds is not yet widespread. Caine et al. (1997) tested the effects of proteases on the ileal digestibility of soybean meal, and their results were disappointing. Beal et al. (1998) used proteases on raw soybeans and observed a significant improvement in daily gain (+14.8%). Feed efficiency, however, was only numerically improved (+4.3%). Dierick and Decuypere (1994), reported that there was a substantial improvement in feed efficiency (larger than what was observed with each enzyme individually) when using proteases in combination with amylases and enzymes that are used to degrade NSP.

Recently, with the advancements in enzyme producing technology as well as a better understanding of the role of enzymes in animal nutrition, the use of enzymes in pig diets will be more widespread and contribute to reduce environmental pollutant from animal manure.

Unlike an aspect that enzymes affect directly nutrient excretion through the improvement of nutrient utilization or inactivation of ANFs, other growth promoters such as 1) antibiotics, 2) probiotics, 3) organic acids and 4) growth hormones can indirectly contribute to reduce environmental pollutants from animal manure. It has been known that growth promoters improve weight gain and feed efficiency in different ways, e.g., metabolic effects, disease control and improvement in nutrient availability (Mordenti and

Table 3. Effects of mill type and particle size on grain characteristics and utilization of nutrients in pigs[1]

Items	Hammer mill		Roller mill	
	800 μm	400 μm	800 μm	400 μm
Growth performance				
Average daily gain, kg	0.93	0.96	0.96	0.92
Gain/feed	0.284	0.308	0.291	0.305
Apparent digestibility, %				
Dry matter[ab]	82.5	86.0	86.6	87.3
Nitrogen	72.1	80.1	76.0	82.6
Gross energy[ab]	81.2	86.7	85.9	87.7
Fecal excretion, g/d				
Dry matter[ab]	517	396	397	347
Nitrogen[ab]	18.4	12.6	16.3	10.9

[1] A total of 128 pigs (55 to 112 kg body weight).
[a] Hammer mill vs. roller mill ($p<0.03$).
[b] 800 μm vs. 400 μm ($p<0.001$). (Wondra et al., 1995)

Piva, 1992). Improvement of feed efficiency obviously involves reduction in nitrogen pollution. At a feed/gain ratio of 3.2 every increase in feed conversion ratio of 0.2 involves an increase of 6% of excreted nitrogen (Dourmad et al., 1992). Han et al. (1995a), reviewing many studies using pigs on feed additives, suggested that the proper use of feed additives could be one of effective ways to reduce nutrient excretion through the their effect on the improvement of feed efficiency or nutrient retention. Table 4 summarized the results from many studies on use of feed additives as environmental friendly agents in swine. As shown in table 4, it seems that antibiotics, probiotics, organic acids and growth hormones have a positive effect on growth performance as well as nutrient excretion.

Antibiotics have been introduced to animal feeds as a growth promoters since last 30 years. The magnitude of antibiotics efficacy highly depends on the environmental condition, management, physiological stage of pigs, nutrient levels in the diets and feeding density. Han et al. (1982) reported that the supplementation of Spiramycin to diet for growing pigs (25 kg BW) at the levels of 25 mg/kg increased weight gain and feed efficiency by 5.9% and 11%, respectively, and reduced dry matter and nitrogen excretion by 17.3% and 18.8%, respectively, compared

Table 4. Effects of various feed additives on growth performance and nutrient excretion of pigs

Initial weight	Levels in diet	ADG (%)	Gain/feed (%)	Excretion (%)		Sources
				DM	N	
Antibiotics						
23.2 kg	25.0 mg/kg[1]	+5.9	+11.0	-17.3	-18.8	Han et al. (1982)
11.3 kg	20.0 mg/kg[2]	+13.7	+16.6	-	-5.6	Min et al. (1992)
16.3 kg	10.0 mg/kg[3]	+5.3	+5.2	-12.8	-5.1	Yu et al. (1985)
15.8 kg	40.0 mg/kg[2]	+6.1	+5.9	-22.5	-12.7	Yu et al. (1985)
Probiotics						
7.0 kg	750.0mg/kg[4]	+3.5	+41.9	-	-	Pollmann et al. (1980)
7.0 kg	220.0mg/kg[5]	+9.0	+49.2	-	-	Pollmann et al. (1980)
14.7 kg	0.03 %[6]	+7.0	+3.8	-15.8	-25.4	Han et al. (1984)
24.2 kg	0.5 %[7]	+2.7	+8.8	-12.6	-4.2	Noh et al. (1995)
34.1 kg	2.0 %[7]	+18.6	+16.4	-	-	Jeon et al. (1996)
Organic acids						
9.5 kg	2.0 %[8]	+4.67	+8.05	-0.12	-1.79	Falkowski and Aherne (1984)
6.2 kg	2.0 %[8]	+14.72	-	-0.87	-4.14	Donald (1991)
9.0 kg	2.0 %[9]	+7.37	+11.03	-0.12	-1.18	Falkowski and Aherne (1984)
Growth hormones						
60 kg	0.5 mg/kg[10]	+23.53	+0.25	-40.79	-37.59	Kang et al. (1994)
63 kg	2.75 mg/kg[10]	+19.8	+0.39	-10.51	-12.39	Hansen et al. (1994)
63 kg	4 mg/kg[11]	+18.51	+0.41	-16.54	-21.4	Hansen et al. (1994)

[1] Salinomycin. [2] Virginiamycin. [3] Flavomycin.
[4] Lactobacilli, [5] Lactic acid.
[6] *Cl. butyricum*, [7] Lactic acid bacteria concentrate.
[8] Formic acids, [9]Citric acid, [10] β-agonists, [11] Porcine somatotropin.

to control. It is generally acceptable that the use of antibiotics to animal feeds could very positively affect animal's growth and feed efficiency. However, recently, with the increasing concerns on the negative impact of use of antibiotics on the human health, it is evitable that the use of anitibiotics to diets for animals will be limited step by step or may be banned in the near future.

Although results are irregular, there is also evidence that probiotics can, in certain conditions, protect young piglets against enteropathogenic disorders and improve growth performance (Giesting and Easter, 1985). From the many studies, it has been recognized that the positive effect of probiotics is related to the creation of an environment unfavorable to pathogenic growth in the gastrointestinal tract (Sissons, 1989; Gibson and Roberfroid, 1995). As a consequence, it is therefore possible that probiotics decrease intestinal microbial catabolism, and have a sparing effect on nutrients (amino acids, carbohydrates) leading to reduced nitrogen flows (Vanbelle et al., 1990). It has been recognized that the efficacy of probiotics has the tendency to be higher in the early age of the pig rather than growing period (Pollman et al., 1980). Some of experiments showed the positive effects of probiotics on nutrient excretion as well (Han et al., 1984; Noh et al., 1995; Jeon et al., 1996). In all of these three experiments, average daily gain and feed efficiency were improved, and dry matter and nitrogen excretion were reduced, which means probiotic has a possibility as a environment friendly agent.

Organic acids may be used for improving growth performance when added to weanling pig diets (Falkowski and Aherne, 1984; Giesting and Easter, 1985; Risley et al., 1991). Dietary supplementation with organic acids has been hypothesized to improve growth performance by reducing gastrointestinal pH and coliform numbers (Scipioni et al., 1978; Kirchgessner and Roth, 1982). Several studies have examined the influence of diet acidification on nutrient digestibility. Kirchgessner and Roth (1982) observed significant improvements in dry matter and nitrogen digestibilities with fumaric acid supplementation. However, the improvements obtained were only about two percentage units. In the study of Eckel et al. (1992), formic acid supplementation improved nitrogen digestibility during one feeding period but had no effect during the subsequent period. In a follow-up study, Kirchgessner et al. (1992) reported improved nitrogen retention in weaner pigs with formic acid supplementation. To the contrary, other researchers (Falkowski and Aherne, 1984; Bolduan et al., 1988; Radecki et al., 1988) have reported no improvements in the digestibility of dry matter and nitrogen when organic acids were fed. This disagreement appears to be related to various factors such as buffering power of diets (Bolduan et al., 1992), age of animals, type of diet and dose and type of acidifiers used (Eckel et al., 1992; Johnson, 1992).

The effects of growth hormones such as β-agonists and porcine somatotropine (pST) which are the partitioning of nutrients among various body tissue are well known (Armstrong, 1991). The results from studies of Husiman et al. (1988) and van der Hel et al. (1988) with pST revealed a significant reduction in nitrogen excretion in crossbred pigs in the 58 to 110 kg range. Reduction of nitrogen was 21%. The improvement in weight gain led to a reduction of six days in breeding time and in feed conversion ratio of 8 to 9% (from 2.63 to 2.41). This operation is capable of reducing phosphorus excretion by 16% (van Weerden and Verstegen, 1989).

Phosphorus excretion control by microbial phytase

The most important ANF in swine nutrition, as it relates to nutrient management, is phytate. Phytate is the main phosphorus containing constituent (phosphorus content 28.2%) of many seeds and tubers and its primary physiological role is a phosphorus store of the plants for germination (Cosgrove, 1980). In general, phytates constitute about 1-2% by weight of many cereals and oilseeds. The major ingredients in pig diets are seeds (cereal grains) or products from seeds (oilseed meal and grain byproducts). However, 60-90% of the phosphorus in these feedstuffs is present in the form of phytate, a compound that pigs do not use well (Cheryan, 1980). Bioavailability estimates of phosphorus in corn and soybean meal for pigs range from 10-30% (Kornegay and Harper, 1997). This phytate phosphorus must be hydrolyzed by an enzyme, phytase, into inorganic phosphorus before it can be used by pigs. Four sources of phytases have the potential to degrade phytate within the digestive tract of pigs: 1) intestinal phytase in digestive secretions 2) endogenous phytase present in some feed ingredients 3) phytase originating from resident bacteria and 4) phytase produced by exogenous microorganisms. Unfortunately, all of these potential sources have proven to have negligible phytase activity for improving phytate availability in nonruminant animals (Kornegay and Harper, 1997).

However, recently, several types of microbial phytases have initiated a new era in the battle to reduce nutrient excretion. From the many studies (Cromwell et al., 1993; Lei et al., 1993; Jongbloed et al., 1990), it has been recognized that it breaks down most of the phytate complex, releasing the phosphorus in it as well as other nutrients (such as zinc and amino acids) bound by it. As a result, it is possible that the total phosphorus levels in the diet are reduced, the efficiency of retention improved and excretion of phosphorus into the environment is decreased.

Kornegay (1996) estimated that phosphorus excretion in the feces could be reduced 25-50% with the use of 200 to 1,000 FTU of phytase. He calculated that for a grower-finisher pigs (from 18 to 108 kg of body weight, consuming a total of 317 kg of feed), phosphorus excretion could be reduced from 0.14 kg without phytase addition to 0.11 kg with phytase addition (if fed NRC (1988) recommended levels of phosphorus 0.45%). In summary of the available literature (Hoppe and Schwartz, 1993 as cited by Kornegay, 1996) on phytase supplementation, it was suggested that 423 FTU/kg was equivalent to 0.1% of phosphorus. Based on the equation generated from many studies using pigs, Kornegay et al. (1998) suggested that the reduction in phosphorus excretion was 15.4 and 18.8%, respectively for 500 and 1,000 FTU/kg of added phytase when compared with the low phosphorus and low phytase activity plant based diets. Based on the research by Hoppe et al. (1991) and Coelho (1994), adding phytase to piglet diets resulted in 45% higher phosphorus availability combined with a 20% reduction in inorganic phosphate thus providing a 30-50% reduction in phosphorus excretion.

Table 5 summarized the results from five studies on effects of using phytase in diets for pigs on growth performance and nutrient excretion. Based on the results present in the table, it is evident that addition of phytase to diet for pigs could result in substantial reduction of phosphorus excretion as well as improvement of performance.

Previously, phytase was too expensive to use as a feed additives. However, this enzyme can now be effectively produced by recombinant DNA techniques, and the cost has decreased. Thus, at the present time the addition of phytase does not appear to add more cost to the diet because it is offset by the savings associated with reducing phosphorus and calcium in the diet. Therefore, the use of phytase will be more common in diet formulation for the pigs with increasing concerns on negative impact of swine production systems on the environment.

Table 6. Ideal amino acid patterns for pigs on three weight ranges (ratios are expressed on a true digestible basis)

Amino acids	Ideal patterns (% of lysine)		
	5~20 kg	20~50 kg	50~100 kg
Lysine	100	100	100
Threonine	65	67	70
Tryptophan	17	18	19
Methionine	30	30	30
Cystine	30	32	35
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

(Baker, 1996)

Use of synthetic amino acids for diet formulation

It is logical that more accurate information will allow more precise feed formulation to meet the amino acid/protein requirements and reduce nitrogen excretion. Such information will enable the nutritionist to apply the concept of 'ideal protein' or 'balanced amino acids'. The ideal protein concept proposes that ideal protein consists of all amino acids in exactly the right proportions for maintenance and lean tissue accretion. According to this concept, requirements of all essential amino acids are expressed as a percentage of lysine (table 6) and each amino acid is equally limiting and excretion of nitrogen is minimized. From a practical standpoint, the ideal protein concept allows for a quick calculation of amino acid requirements and flexibility of diet formulation as long as the lysine

Table 5. Effects of phytase on growth performance and nutrient utilization in pigs

Range (FTU[1])	Age or weight	ADG (%)	Gain/feed (%)	Utilization (%)			Ref.*
				DM	N	P	
800	45.0 kg	-	+2.86	+2.86	-	+73.27	1
500	20.7 kg	+11.94	+6.10	-	-	+23.00	2
1,000	20.7 kg	+20.90	+6.11	-	-	+33.00	2
500	10.2 kg	+15.56	+9.76	-	+7.46	+12.86	3
1,000	37.0 day	-	-	-0.24	+13.63	+54.41	4
1,000	18-74 day	+8.49	+1.49	-6.3		+26.00	5
500	47-74 day	+7.24	+3.62	+3.62	-3.11	+20.29	5

[1] 1 FTU is equal to 1 μmol of otho-phosphate liberated from 1.5 mmol of Na-phytate within 1 min. at 37℃ and pH 5.5.
* 1=Mroz et al. (1994); 2=Cromwell et al. (1993); 3=Young et al. (1993); 4=Simons et al. (1990); 5=Kwon et al. (1995).

Table 7. Effects of synthetic amino acid supplementation on growth performance, feed conversion and nutrient excretion in pigs compared to control diets

CP level C-L[1] (%)	Added (%)				Weight (kg)	ADG (%)	G/F (%)	Excretion (%)*			Ref.**
	Lys	Met	Thr	Trp				DM	N	P	
18-16	0.10	-	-	-	9-25	+2.8	+1.5	-16.7	-10.6	-14.7	1
18-16	0.20	-	-	-	9-25	-1.3	+0.0	-22.5	-17.7	-20.9	1
18-16	0.40	-	-	-	9-25	+1.5	+1.0	-16.3	-4.0	-15.8	1
14-14	0.15	-	-	-	25-30	+14.5	-	-	-33.7	-	2
14-14	0.30	-	-	-	25-30	+36.0	-	-	-31.7	-	2
14-14	0.45	-	-	-	25-30	+42.3	-	-	-38.5	-	2
16.9-15.6	0.24	-	-	-	44.2	-	-	-	-13.9	-	3
14.6-13.5	0.22	-	-	-	84.1	-	-	-	-19.3	-	3
16-12	0.34	-	0.16	0.07	22.3	-3.6	-4.0	-4.4	-29.3	-	4
18-15	0.28	-	-	-	14-26	-8.7	-7.1	-0.1	-6.7	+1.6	5
18-15	0.28	0.04	-	-	14-26	-7.1	-6.2	-1.1	-7.6	-0.6	5
18-15	0.28	-	0.12	-	14-26	-3.5	-3.5	-4.7	-11.0	-1.4	5
18-15	0.28	0.04	0.12	-	14-26	+0.2	-1.0	-7.3	-17.2	-0.6	5
18-15	0.28	0.04	0.12	0.02	14-26	+0.6	-1.0	-7.9	17.7	-0.6	5

* Compared to control treatment.
[1] Control high protein diet - Low protein diet.
** 1=Han et al. (1995b) ; 2=Hahn et al. (1995) ; 3=Gatel et al. (1992) ; 4=Kerr and Easter (1995) ; 5=Jin et al. (1998)

requirement of the pig is defined.

A large part of the nitrogen losses are associated with inefficiencies of digestion and absorption but more generally in protein synthesis after absorption, so the excretion of nitrogen in feces and urine may be influenced by dietary manipulation. The use of synthetic amino acids in diet formulations to replace intact protein is very effective in reducing pollutants from animal manure. Through the use of synthetic amino acids, dietary crude protein levels could be decreased, thus reducing nitrogen excretion (Bolduan et al., 1992). Providing diets with highly available synthetic amino acids may improve absorption and protein synthesis. This will reduce the amount of nitrogen in the diet, which will in turn reduce nitrogen excretion. A simple means of improving dietary amino acid balance is to partially replace some of the standard protein sources (e.g., soybean meal) with purified synthetic amino acids. If these diets are properly formulated and produced, they should support at least the same levels of performance as compared to corn-soybean based diets (Tuitoek et al., 1997).

Effects of synthetic amino acids on the growth and nutrient excretion reported in the literature over the last two decades are summarized in table 7. This summary shows that reduction of 2 to 4% unit (U) of dietary protein with supplemental amino acid (AA) can reduce dramatically nitrogen excretion. Lenis (1989) reported that lowering dietary crude protein level for growing-finishing pigs by 2 percentage U reduced nitrogen excretion by approximately 20%. In a review of literature, Lenis and Jongbloed (1999) concluded that even larger reductions in dietary protein level are possible if appropriate levels of amino acids are supplemented to low protein diets. Carter et al., (1996) reported that reduction of dietary protein by four percentage units with addition of lysine (LYS), methionine (MET), threonine (THR) and tryptophan (TRP) results in a significant reduction (34%) in nitrogen excretion from growing-finishing pigs (figure 1).

Lenis and Jongbloed (1999) stated that reducing dietary crude protein levels with the supplementation of amino acids can reduce nitrogen excretion as well as manure volume. Because reduced dietary protein levels usually involve a reduction of the dietary level of soybean meal in the diet, and because soybean meal contains approximately 2.0 to 2.2% potassium, this will result in a significant decrease of the dietary potassium level and consequently in a lower potassium excretion. The lower dietary levels of protein and potassium may also lower water intake when available *ad libitum* to the pigs, which will reduce manure volume.

It should be noted that there have been some results showing negative effect on growth performance and carcass characteristics when even lower crude protein (CP) diets with supplemental AA were fed to pigs. Cromwell et al. (1996) showed that pigs can perform optimally at 4 percentage units crude protein reduction with supplementary amino acids, but carcass leanness was reduced. Tuitoek et al. (1997) also found increased fat content in the carcass and reduced gain and feed efficiency in pigs fed diets with protein levles reduced by 4 percentage U even when the low protein diets with synthetic amino acids (lysine, threonine, tryptophan, isoleucine, and valine) were fed to meet ideal amino acid ratios.

The use of synthetic amino acids to lower CP diets is associated with cost factor as well as potential reduction of nitrogen excretion. When some of the soybean meal is replaced with lysine · HCl, both feed cost and nitrogen excretion are reduced. But there may be a limited economical feasibility of using various amino acids to reduce dietary protein levels. The potential of the use of synthetic amino acids is likely to be closely related to prices of the soybean meal and synthetic amino acids.

FEEDING MANAGEMENT

Feed waste control

The reducing feed waste can be the first step to control nutrient excretion. Poor feeder design and presentation of feed can lead to the wasting of animal feed. Gonyou and Lou (1998) reported that feed wastage was typically 5 to 6% but there would be much larger ranges for field conditions (1.5% to 20%). Although little research has been conducted to evaluate the effect of feed wastage on environmental pollution, it cannot be ignored. Since wasted feed generally falls into the manure storage areas, its contribution to waste can be estimated by making some assumptions. For example, if feed wastage is 5% on average during the growing-finishing phase (which is a low estimate), and the animal utilizes approximately 30% of the nitrogen fed, then feed wastage contributes 7.5% of the nitrogen in manure. For minerals such as copper, zinc, and phosphorus, the contribution of feed waste to manure is similar.

Feed waste is strongly influenced by type of the feed. Mash feed tends to cling to the animals chin and nose, ultimately leading to waste. Gonyou and Lou (1998) observed that each time the pig leaves a feeder it takes 1.5 grams of feed with it. Given that the pig typically accesses the feeder 60 times per day, this theoretically could amount to wasting 90 grams of feed. Pigs also tend to root through the feed, which in poorly designed feeders lead to the waste of 3.4% of the feed (Gonyou and Lou, 1998). Pelleting feeds reduces both forms of feed waste. Based on data from Vanschoubroeck et al. (1971), it may be estimated that pelleting reduced feed waste with approximately 5%.

Traditional recommendations are that feeders should be designed such that it is more difficult to push feed out of the feeder, and even more importantly, the feeder should be managed such that only a small amount of feed is present in the feeder (van Kampen, 2000). This does require that feeders are easy and accurate to adjust. A general guideline is that feeders should be managed such that only 50% of the bottom of the feeder is covered. This not only prevents feed waste, but it also reduces spoilage of feed.

In addition to feed waste, water waste also can not be ignored. If manure is to be transported for land application as a fertilizer or is to be processed, it is important to reduce the water content of the manure to minimize transport or processing costs. For the reduction of water waste several common-sense management practices are available. For instance, water leaks should be fixed immediately. As for cleaning, barns should be soaked with a foaming agent and subsequently cleaned with a high-pressure washer. Drinking water can be supplied to pigs via many different routes. It is considered that conventional water nipples do not efficiently deliver water to the pigs (it is interesting to observe how much water coming out of a nipple never gets into the pig). Installing cups under the drinkers, although problematic to keep clean, will reduce water usage. For example, Den Brok and van Cuyck (1993) demonstrated that changing the water supply from a drink cup to a feeder with an integrated drink nipple resulted in a 33% decrease in manure production (from 400 gallons to 250 gallons per animal place per year).

The application of wet-dry feeding system can be considered as one of effective ways to reduce feed waste. Han (1998) reported that wet-dry feeding to pigs (20 to 82 kg) could result in reduction of feed waste by 60% compared to pellet diet feeding and wet-dry feeding could improve the environment of pig house through the reduction of dust production (table 8).

In summary, to reduce feed and water wastes swine producers should pay attention to choose well installed feeders and water supply system that are designed to minimize feed waste, adjusting and cleaning feeders frequently. Using pelleted feeds or wet-dry diets rather than mash feed can be considered as a good ways to minimize feed waste.

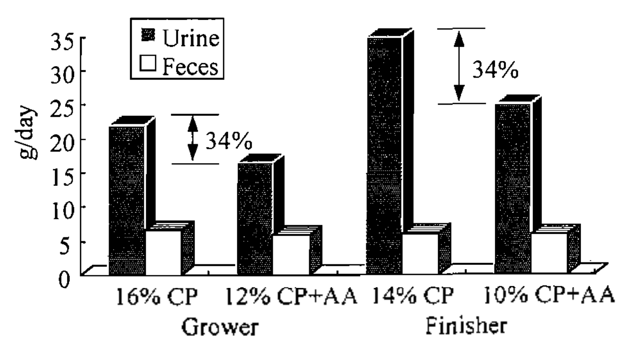

Figure 1. Effects of reduced dietary protein by 4% unit and supplementation with 0.30% Lys, 0.1% Met, 0.1% Thr and 0.05% Trp on N excretion of growing-finishing pigs (Carter et al., 1996)

Table 8. Effects of wet-dry feeding on growth performance and feed waste of pigs (20 to 82 kg)

Items	Wet-dry diets	Pellet diets
ADG, g	630	619
Feed/gain	2.82	2.90
Feed waste per pig, g	23.4	63.0
Dust production in pig house, mg/m^3	0.5~14	5.1~23

(Han, 1998)

Phase feeding

Recently, it has been recognized that phase feeding could be used to reduce nitrogen and phosphorous excretion by feeding pigs in better agreement with age and physiological state (Jongbloed and Lenis, 1992; Paik et al., 1996). Phase feeding is a term used to describe the feeding of several diets for a relatively short period of time in order to closely meet the pigs' nutrient requirements. With current feeding strategy, it is not likely to meet the animals' nutrients requirement which rapidly changes according to their ages. By phase feeding, the nutrient requirements could be met more closely and it provides a more economical and environmentally sound feeding program for the pig.

Jongbloed and Lenis (1992) reported that growing pigs use only about 30 to 35% of ingested nitrogen and phosphorus. These are important information to emphasize the need of phase feeding strategies to allow providing dietary nitrogen and phosphorus in close accordance with the animals' requirement. The introduction of one or more additional feeds will avoid over or under feeding condition for growing-finishing pigs and help balance amino acids and digestible phosphorus in the diet to the requirements of the pig, as a results, less nitrogen and phosphorus are excreted. Namely, when diets are precisely formulated to meet the nutrient requirements (especially protein and amino acids) of pigs, nitrogen excretion can be reduced due to decreased dietary excess and improved nutrients utilization.

Lenis (1989) calculated the reduction in nitrogen excretion by changing from one feed system that is common in Europe to a two phase feeding regimen. Koch (1990) reported that by matching the feed's nutrient composition to pigs' requirement at a given age and weight through phase feeding system, nitrogen excretion could be reduced by 14% and nitrogen retention could be improved by 10%. Lenis (1989) reported that nitrogen and phosphorus excretion could be reduced 6% by two phase feeding compared to single phase feeding.

Recently, our research team has conducted a series of experiments to determine optimal number of phases for finishing period and evaluate effects of phase feeding on growth performance and nutrient excretion of finishing pigs. Lee et al. (2000a) have compared four phase feeding regimens by using four different dietary protein patterns (16% CP, one phase feeding; 16% and 12% CP, two phase feeding; 16%, 14% and 12% CP, three phase feeding regimen; 16%, 14.7%, 13.4% and 12% CP, four phase feeding, respectively). The results revealed that three phase feeding regimens resulted in 12% lower nitrogen and dry matter excretion than one phase feeding regimen without any

Table 9. Effects of different feeding regimens[1] on the growth performance and nutrient excretion of finishing pigs

Items	One phase	Two phase	Three phase	Four phase	MSE[2]
Overall period (54 to 104 kg)					
Initial weight (kg)	54.21	54.25	54.15	54.17	0.10
Final weight (kg)	103.45	103.41	104.38	104.16	1.83
Average daily gain (kg)	0.771	0.771	0.789	0.783	0.03
Average daily feed intake (kg)	2.53	2.54	2.60	2.52	0.07
Feed/Gain	3.28	3.28	3.29	3.22	0.09
Nutrient excretions					
Dry matter (g/day)	282.8^{a}	270.3^{ab}	248.4^{b}	263.4^{ab}	26.60
Nitrogen (g/day)	8.9^{a}	8.0^{b}	7.8^{b}	7.9^{b}	0.99
Phosphorus (g/day)	6.29	6.43	6.03	6.18	0.58

[1] One phase : feeding single diet with CP 16% for 54 to 104 kg of BW.
Two phases : feeding two diets with CP sequence (16%-12%) for 54 to 80 and 80 to 104 kg, respectively.
Three phases : feeding three diets with CP sequence (16%-14%-12%) for 54 to 70, 70 to 90 and 90 to 104 kg, respectively.
Four phases : feeding four diets with CP sequence (16%-14.7%-13.4%-12%) for 54 to 65, 65 to 80, 80 to 95 and 95 to 104 kg, respectively.
[2] Mean standard error.
[a,b] Means in the same row with different superscripts differ ($p<0.05$).

(Lee et al., 2000a)

Table 10. Effects of supplementation of synthetic amino acids to diets on growth performance and the nutrient utilization of finishing pigs

Items	Control[1]	Con+L	Con+LMT	Con+LMTT	SE[2]
Growth performance					
Initial weight (kg)	55.79	55.73	55.76	55.76	0.65
Final weight (kg)	107.08	106.04	104.03	103.64	1.07
Average daily gain (kg)	0.827^{a}	0.812^{ab}	0.778^{bc}	0.772^{c}	0.01
Average daily feed intake (kg)	2.61	2.56	2.51	2.52	0.03
Feed efficiency	3.15	3.16	3.22	3.26	0.02
Nutrient utilization					
Excretion (g/day)					
Dry matter	272.19	266.80	270.39	268.65	3.43
Urinary nitrogen	20.52^{a}	17.01^{b}	15.45^{c}	15.20^{c}	0.65
Fecal nitrogen	8.42	8.05	8.04	7.48	0.28
Total nitrogen	28.95^{a}	25.06^{b}	23.50^{bc}	22.69^{c}	0.76
Fecal phosphorus	4.65	4.57	4.39	4.24	0.07
Nitrogen intake (g/day)	50.61	47.64	44.20	42.82	-
Nitrogen retention					
Daily nitrogen, g	21.66	22.57	20.70	20.12	0.44
Nitrogen % of nitrogen intake	43.51	47.90	47.32	47.64	0.81

[1] Dietary treatments include 1) control (16-14-12% CP), 2) Con+L (15-14-13% CP with identical lysine levels with the control), 3) Con+LMT (14-12-11% CP with identical lysine, methioine and threonine levels with the control) and 4) Con+LMTT (13-11-9% CP with lysine, methionine, threonine and tryptophan levels with the control).

[2] Pooled standard error.

[a,b,c] Values with different superscripts within the same row are significantly different ($p<0.05$). (Lee et al., 2000)

deterioration of growth performance and carcass characteristic (table 9).

In continuous study, Lee et al. (2000b) conducted an experiment to investigate the effects of different dietary protein sequences (17-15-13% CP, 16-14-12% CP and 15-13-11% CP) on growth performance of finishing barrows and gilts. They reported that there was no interaction between sexes and dietary CP levels on growth performances and suggest that 16%-14%-12% dietary CP sequence is desirable in the sense of economics and environment for practical three phase feeding regimen for finishing period. In another study, Lee et al. (2000c) investigated the effect of low CP diet supplemented synthetic amino acids on growth performance and nutrients utilization of finishing pigs under three phase feeding regimen and to determine the safety margin for dietary protein level to minimize nitrogen excretion without sacrificing performance of pigs (55 to 105 kg). Dietary treatments were as follows; 1) control (16-14-12% CP), 2) Con+L (15-14-13% CP with identical lysine levels with the control), 3) Con+LMT (14-12-11% CP with identical lysine, methioine and threonine levels with the control) and 4) Con+LMTT (13-11-9% CP with lysine, methionine, threonine and tryptophan levels with the control). As shown in table 10, for the overall period (55 to 105 kg), Con+L group showed similar growth performance to the control group, but resulted in 13.4% lower nitrogen excretion compared to the control group. Con+LMT and Con+LMTT groups also resulted in much less nitrogen excretion (18.8 and 21.6% resuction, respectively) compared to the control, but resulted in significant reduction of growth performance. This results indicate that reducing dietary CP level by 1% U and supplementing only lysine at each phase could obtain similar growth performance compared to control and could be very beneficail feeding strategy for finishing pigs under three phase feeding regimen in both environmental and economical aspects.

The results from our studies suggest that phase feeding regimen which enable pigs to closely meet their nutrient requirement without over-feeding is a very effective method to reduce pollutant excretion without affecting animal growth performance.

Sex split feeding

Feeding barrows and gilts separately, known as split sex feeding, can also decrease excretion of nitrogen and phosphorus. It is also well known that barrows consume more feed and gain body weight more rapidly than gilts (Ekstrom, 1991). Conversely, gilts are more efficient in converting feed to body weight gain and deposit a higher percentage of muscle and a lower percentage of fat tissue in their carcass than barrows (Ekstrom, 1991; Cromwell et al., 1993).

Because gilts have a greater accretion rate of lean tissue and a lower feed intake than barrows, many researchers have suggested that gilts require a higher level of dietary CP (amino acids) than barrows to maximize rate and efficiency of growth and carcass leanness (Cromwell et al., 1993). Therefore, it is likely that penning barrows and gilts separately and feeding them diets that more closely meet their nutrient requirements are more effective feeding system for finishing pigs than a feeding system in which barrows and gilts were mixed in the same pens.

CONCLUSION

Over the last decade, animal production has expanded significantly. However, with this expansion, environmental issue related to animal production has been increased. It is noted that controlling environmental pollutants from animal manure through the proper feeding and management strategy is very important to make animal industry sustainable in the 21 th century. In this manuscript, several effective feeding and management systems to reduce environmental pollution in swine production have been briefly introduced. It is evident that several approaches described above are effective to reduce excretion of pollutants from animal manure. However, incessant study to figure out more effective ways to control excretion of pollutants from animal production should be needed.

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