Midwest Swine Nutrition Conference Proceedings

Indianapolis, Indiana — September 4, 2002

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Purdue University

THE OHIO STATE UNIVERSITY

MICHIGAN STATE UNIVERSITY FOUNDED 1855

UK

Visit Ohio State University Extension's Web Site "Ohioline" at:
http://ohioline.osu.edu

Keith L. Smith, Associate Vice President for Ag. Adm. and Director, OSU Extension

TDD No. 800-589-8292 (Ohio only) or 614-292-1868

9/02

Contents

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Nutritional Problems Encountered In The Field By A Practicing Swine Veterinarian

Larry Rueff, DVM, Swine Veterinary Services
Greensburg, IN 47240

Summary

Nutritional problems encountered in the field by practicing swine veterinarians are the result of different types of swine operations they serve and the geographical areas the farms are in. Common problems encountered with sow feeds in gestation and lactation typically have more to do with sow feed intake or total energy intake than they do with the formulation for amino acids, minerals, and vitamins. Getting producers to utilize management techniques to increase energy intake can be difficult. Water is still a forgotten nutrient and can limit the feed intake in pigs through out all stages of the operation. Mycotoxins are being observed more and more frequently and are significant aspects of nutritional problems in swine farms. Finally, it is important that the right diet is placed in front of the right pig. Pigs are often times given too simple of diets for the stage of production that they are currently in.

Introduction

In looking at nutritional problems that are encountered in the field one needs to remember that practicing veterinarians are much like a feed sample. Results one finds are based on the sample that their experience represents. My practice experience consists of 23 years of working with pig producers predominantly in the Midwest. Over the years the swine customer and their facilities have changed as the pig industry has changed. My clients have changed from small farms that raise and feed their own grains to include large sow systems greater than 5,000 sows that purchase their grain. These farms may often times have multiple feed processing centers.

The following are some common nutritional problems encountered in the field.

Sow Energy and Feed Intake

As sows were moved from outside dirt lots to inside confinement facilities a number of other trends occurred simultaneously. One was that we moved from crossbred sows with colored breeds to essentially an all white line females that were more productive and leaner. Producers brought sows inside and felt, with some justification, that the amount of feed fed could be reduced if the animals were in environmentally controlled buildings. With feed not being wasted by being trampled into the dirt or mud and sows being fed individually, this seemed to have some merit. However, this seems to have gone too far in some herds. I encounter sow herds that under feed their sows from an energy standpoint. In most cases the protein, calcium, phosphorus, and vitamin/minerals in the diet composition are adequate. The total amount of energy fed is the main problem on most swine farms. This could be referred to as just not enough groceries. This problem occurs in both gestation, but particularly in lactation.

One of the difficulties when finding a herd with these issues is convincing the producer that they are not getting enough total feed intake into the sow herd. In gestation, as sows get thin, one must tremendously over compensate daily feed intake to get sows back into the right body condition. This over compensation must be by as much as an increase of 25% to 30% in daily gestation feed for a period of two months to get body condition back to normal. We must radically over compensate if we want to solve the body condition problem. Increasing intake by ½ pound per day will not get the job done!

Lactation intake is another problem. It is a rare farm that I can't walk into at 10:30 in the morning and put feed in the feeders and have the sows get up and want to eat. Producers and employees constantly restrict sow intake by not giving the sows as much feed as possible. Milk production, and thus pig weaning weight suffers when lactating sows are not fed all the feed they want. Subsequent wean to service interval and conception failure are next on the clinical problem list that start to occur. This is a simple problem with a not always simple solution. Getting producers to implement procedures to increase lactation feed intake is not always easy. Old habits and assumptions don't die easy. Three time a day feeding does work!

Water Intake

As I was taught in Nutrition 221 at Purdue University in 1973, water is the forgotten nutrient. It still is. I observe farrowing houses with inadequate water flow to stimulate and increase large feed intake in lactation. Sows need to have a flow rate of 1500 ml of water per minute to maximize water consumption. Wet feeding in farrowing houses, though time consuming, will result in increased lactation feed intake. Nurseries should have 500 ml water flow per minute and finishers should have 800 to 1000 ml per minute. Nursery and finishing pens should have two different water sources within the pen to maximize water intake. It appears from some records and observations that this is particularly valuable in finishing barns in summer months.

Mycotoxins

When I first started practice in 1979, I heard a lot of reference to molds and mycotoxins. I encountered lots of mold. Mycotoxins were not so common and are not the same issue as molds. Producers seemed to be confused by this. However, as the hog industry has changed and producers have to purchase grain, I now run into situations where mycotoxins can be present. The two most common mycotoxins I see in the Midwest are Vomitoxin (Deoxynivalenone) and Zearalenone.

Vomitoxin is very interesting. Clinically my observations match up with the following feed analysis:

1 ppm	Some feed refusal
2 ppm	Increased feed refusal and possibly vomiting
> 2 ppm	50% to total feed refusal

The testing that we do through lab analysis for vomitoxin usually corresponds quite well with the clinical results we see in the animal.

Weaned Pigs

This could sometimes be titled "Does Anyone Have A Scale?" In a group of weaned pigs, it is not unusual for me to see the whole group of pigs on the same diet even though there is a two week age difference amongst the group. Often times there is as much as 6 to 7 pounds difference between the biggest and lightest pigs at weaning. Typically, in some nurseries 15% to 20% of the pigs are on a diet that is too simple for their digestive tract. Weighing pigs can help producers understand what a pig actually weighs and thus what diet they need to be on. We have the nutritional knowledge to really make pigs perform. We must make sure that the proper diet is placed in front of the pig.

New Developments Regarding the Pig's Need for Vitamins E, A, and C

Don Mahan, Professor, Animal Sciences
Ohio State University, Columbus, OH 43210

Summary

The antioxidant status of the weaned pig appears to be important in reducing mortalities and in enhancing nursery pig performances. Diets for weaned pigs should contain vitamin E at 40 to 60 IU/ kg. With added fat (5%) dietary vitamin E absorption will be enhanced with greater retention of α-tocopherol in the tissues. Excess dietary vitamin A is common in most swine vitamin premixes, but it can be detrimental to the weaned pig by reducing the absorption and tissue retention of α-tocopherol. It is suggested that vitamin A not exceed NRC recommendations by more than 1-fold. Vitamin C is necessary to regenerate α-tocopherol and is an important antioxidant in the body. The weaned pig cannot synthesize adequate vitamin C for at least 2 to 4 weeks postweaning and thus seems to need a dietary supply until at least the body synthesizes it's own supply. Supplementing the diet with 150 ppm of a stabilized form of vitamin C is suggested.

Introduction

The animal has a need for several antioxidants, some of which are needed in the diet, whereas others can be synthesized by the body. Vitamin E is one of the nutrients serving as an antioxidant that has a dietary requirement. Although Se is considered an antioxidant (when in the enzyme glutathione peroxidase), it's dietary level is regulated by the FDA, whereas vitamin E's level is not regulated. Because vitamin E is critical in maintaining the animal's health and cellular functions, the dietary level provided is of great importance. Other vitamins have a role in maintaining the body's vitamin E status, namely vitamins A and C. New developments with these vitamins may be particularly helpful in formulating diets for the weaned pig.

Upon eating feed the weaned pig digests and absorbs the nutrients contained within the diet, but then the absorbed nutrients undergo metabolism. Although we normally think of animal's depositing muscle, fat, and bone, there are several metabolic intermediates that occur prior to the development of these tissues that can be quite detrimental to the pig if they are not neutralized or voided by the body. Perhaps one of the most detrimental products is a form of oxygen that results from the metabolism of dietary starches, fats, and proteins. If this oxygen not combined with hydrogen to produce water, the oxide produced can destroy cell membranes and cause the death of the animal. It is a common occurrence today that the modern, larger and faster growing pigs are suddenly found dead in the pen with no apparent clinical symptom of a problem. This may often times be attributed to the poor antioxidant status of the pig. The postweaned pig seems to be particularly vulnerable to this situation because of its rapid growth rate, but deaths also occur during the grower finisher phase. At least part of this mortality problem may be associated with the inability to handle the toxic products of metabolism.

The body has several mechanisms to prevent the buildup of toxic oxygen resulting from the metabolism of nutrients. One of the primary functions of vitamin E is its antioxidant role, but it is also closely associated with selenium, vitamin C, vitamin A, zinc, and iron. Because vitamin E is involved with antioxidant properties associated with cellular membranes or the lipoprotein matrix of the cell, this report will evaluate not only its role in quenching the detrimental metabolic intermediates of the body but will also evaluate the role of vitamins A and C and their relationships with vitamin E. That does not negate the role of the other antioxidants used by the body, for each has a specific role at a specific site within the cell or at the cellular level, and all are extremely important in maintaining a healthy and productive animal.

Vitamin E.

This vitamin is found in different forms in plant tissue and grains, but it's most biologically active form is d-α-tocopherol. Most grains are low in this form of vitamin E or are destroyed upon storage, and therefore the vitamin E content of most cereal grains cannot be counted upon for contributing much vitamin E to the pig's requirement. Vitamin E is usually synthesized commercially as dl-α-tocopherol, but it must be stabilized from being oxidized. This is accomplished by the addition of an acetate molecule onto the active site of vitamin E when it is manufactured. The stabilized commercial product is thus called dl-α-tocopheryl acetate (all-rac-α-tocopheryl acetate), whereas the natural form of the vitamin when stabilized is called d-α-tocopheryl acetate (RRR-α-tocopheryl acetate). The biological activity of the natural vitamin E form is reportedly somewhat higher than the commercial synthesized form, but both forms are good dietary sources of vitamin E.

Sow milk can be high in α-tocopherol if the sow is fed adequate levels of vitamin E. The pig can enter the postweaning phase at a relatively high vitamin E status if the sow is adequately fed a recommended level of vitamin E. Upon weaning, however, serum α-tocopherol concentration declines precipitously in the young pig and if it declines too much it can result in the deficiency onset which could produce the death of the pig. The vitamin E/Se deficiency is most frequently reported during the initial weeks postweaning but also during the grower finisher phase. It is this high mortality and its association with the vitamin E/Se deficiency syndrome that many feed companies have incorporated high levels of supplemental vitamin E during this phase to reduce the deficiency onset. Supplemental Se cannot be added to the diet beyond 0.30 ppm so it appears that the best option may be to increase the vitamin E level.

The NRC (1998) requirement for vitamin E is 16 IU/kg diet from a body weight of 5 to 10 kg, and 11 IU/kg diet from 10 kg to market weight. Most commercial feed companies, recognizing the problem of sudden deaths postweaning, mulberry heart, gastric ulcers, and other clinical problems have therefore incorporated high dietary levels of vitamin E to prevent the deficiency onset. Dietary levels as high as 200 IU vitamin E/kg have relieved the deficiency problems somewhat, but they have not prevented the vitamin E/Se deficiency.

The NRC (1998) requirement for vitamin A is 2,200 IU/kg for the weaned pig from 5 to 10 kg body weight and declines to 1,750 to 20 kg body weight and is lower for the grower finisher pig.

A recent survey by a large vitamin manufacturer has reported that dietary vitamin A is often times incorporated into the weanling pigs diet at five times the requirement level with some being in even greater excess (Coehlo, 2000). The effect of high dietary levels of vitamin A on other young animals has resulted in a reduction in vitamin E absorption, and if confirmed in the pig the use of high dietary levels of vitamin A could be harmful to the weaned pig.

The effectiveness of high levels of both vitamin A and E were recently investigated with weanling pigs. The results of that experiment presented in Table 1 demonstrated that when either vitamin E or A were increased by 6-fold higher than NRC (1998), there was neither a beneficial nor a detrimental effect on pig performance during the nursery period.

When vitamin E was increased in the diet, there was a rise in serum α-tocopherol concentration, but a rise in serum vitamin A (i.e., retinol) also occurred when dietary vitamin A was increased (Table 1). However, the results also demonstrated that serum α-tocopherol was adversely affected by dietary vitamin A level. A decline in serum α-tocopherol occurred when vitamin A was increased above NRC (1998) standards, suggesting that excess vitamin A affected the absorption and possible retention of vitamin E in the tissues of pigs.

A second experiment was therefore conducted where a constant level of vitamin E was fed (i.e., 40 IU/kg) but using either the natural or the synthetic form of the vitamin, each supplemented with various levels of vitamin A. This was done to evaluate whether the natural or synthesized form of vitamin E would be affected differently by excess vitamin A. Table 2 demonstrated that higher levels of vitamin A did not have a beneficial or detrimental effect on pig performance, responses consistent with the results of experiment 1, but there was clearly an effect on the absorption and retention of vitamin E, responses also consistent with the results of experiment 1.Both the liver and serum α-tocopherol concentrations declined when dietary vitamin A was increased suggesting that the vitamin E status in the weaned pig was compromised. Both forms of vitamin E seemed to precipitate the same response.

Vitamin E is considered a fat soluble vitamin after the acetate moiety is removed during the digestive process. The released vitamin E is therefore presumed to be absorbed along with the other fat

Table 1. Effect of High Dietary Levels of Vitamin A and E for Weaned Pigs

	Vitamin E, IU/kg		Vitamin A, IU/kg		
Item	15	90	2,200	13,200	SEM
No. of pigs [a]	140	140	140	140	-
Daily gain, g	413	421	413	421	5
Daily feed, g	671	670	670	672	5
Gain:feed ratio, g/kg	621	628	616	628	6
Serum retinol, μg/mL [b]					
35-day	0.46	0.47	0.42	0.51	0.01 [c]
Serum α-tocopherol, μg/mL [b]					
35-day	.72	2.00	1.56	1.16	0.08 [cde]

[a] Initial weight of pigs averaged 6.3 kg. The study was conducted for a 35-day period in seven replicates.
[b] Each mean represents 100 pigs from 5 replicates.
[c] Vitamin A level response ($P < 0.01$).
[d] Vitamin E level response ($P < 0.01$).
[e] Vitamin E x Vitamin A interaction ($P < 0.05$).

Source: Ching et al. (2002)

soluble products of digestion. Many weanling pig diets do not normally contain added fat because of it higher cost and the low utilization of dietary fat by the weaned pig. The effects of various levels of vitamin E with or without the inclusion of 5% added fat demonstrated in Figure 1 that serum α-tocopherol concentration was increased with the addition of added fat. The addition of added fat did not seem to affect the level of α-tocopherol in the liver or heart tissue until 60 IU vitamin E was fed, whereupon its concentration increased (Figures 2 and 3). A higher tissue concentration of α-tocopherol can serve as a more active source of α-tocopherol in preventing the quenching of prooxidants. The addition of vitamin E on tissue α-tocopherol concentration seemed to plateau at about 40 to 60 IU, dietary levels substantially higher than current NRC (1998) standards.

Vitamin C.

This vitamin is also an active antioxidant that is used largely as an antioxidant in the aqueous phase of the cell's cytoplasm, but it can also can be an antioxidant in the lipoprotein portion of the cell. Vitamin C serves as an active "H" donor in regenerating vitamin E once it has been oxidized, returning the vitamin E molecule to its active form. Thus the body has a need for vitamin C in both its antioxidant role, but also in regenerating vitamin E from an inactive to an active form.

Over the past five decades, we have all thought that the pig began to synthesize vitamin C at approximately one week of age (Braude et al., 1950). Because colostrum and milk contained relatively high levels of vitamin C (i.e., ascorbic acid), there was no need to supplement the pigs diet with vitamin C. However, previous research in the weanling pig area where vitamin C was added to their diets had resulted in inconsistent responses with some research showing a beneficial response while others have shown

Table 2. Effect of High Dietary Levels of Vitamin A and Natural or Synthetic Vitamin E in the Diets of Weaned Pigs.

Item	Vitamin E source:	Natural [a]			Synthetic [b]			
	Vitamin A level:	2,200	13,200	26,400	2,200	13,200	26,400	SEM
No. of pigs		30	30	30	30	30	30	-
Daily gain, g		345	363	365	354	350	343	19
Daily feed, g		540	556	563	562	550	538	28
Gain:feed, g/kg		639	653	648	630	636	638	23
Serum retinol, µg/mL								
Initial		0.26	-	-	-	-	-	-
35-day		0.51	0.58	0.60	0.51	0.59	0.61	0.03
Liver retinol, µg/g								
Initial		0.95						
35-day		1.85	23.7	46.5	1.3	23.6	54.0	2.6
Serum α-tocopherol, µg/mL								
Initial		1.51	-	-	-	-	-	
35-day		1.46	1.32	1.21	1.07	1.14	0.93	.17
Liver α-tocopherol, µg/g								
Initial		4.5						
35-day		2.7	2.1	2.0	2.7	2.0	1.5	.4

[a] Natural vitamin E = d α-tocopheryl acetate
[b] Synthetic vitamin E = dl α-tocopheryl acetate

Figure 1. Effect of Dietary Fat and Vitamin E on Serum Tocopherol

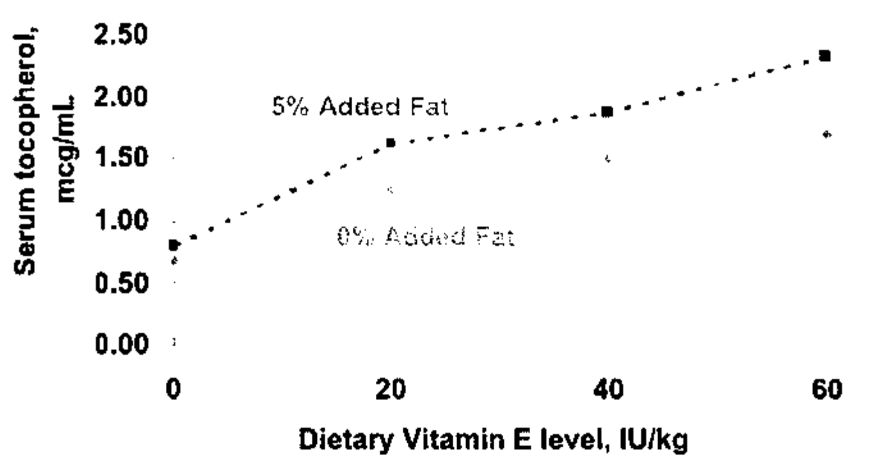


Figure 2. Effect of Dietary Fat and Vitamin E on Liver Tocopherol

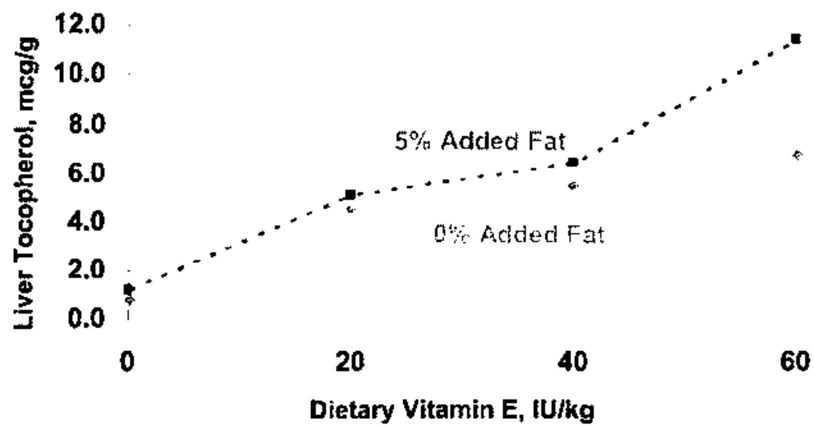
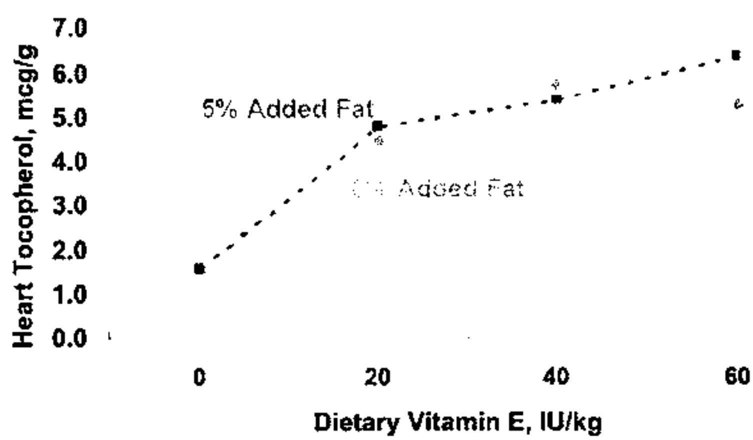


Figure 3. Effect of Dietary Fat and Vitamin E on Heart Tocopherol



no benefit. Stress has been suspected of increasing the physiological need for vitamin C, and vitamin C therefore could be beneficial in some instances, whereas in other situations it may not results in a growth response.

We conducted an experiment evaluating the activity of the enzyme in the young pig from 60 days of fetal development through weaning to evaluate precisely when the vitamin was synthesized in the young pig and if a supplemental level was needed in nursery diets. In general, we demonstrated that the young fetal pig at 60 days of development clearly had the ability to synthesize ascorbic acid in the liver from early pregnancy, but that its activity declined toward the end of gestation and through lactation. It is during the period when the sow transfers the vitamin through the placenta and later through the mammary glands into the milk that the vitamin C synthesis by the young pig seems to be restrained. It appears that while the pig is exposed to a maternal source of vitamin C either through the maternal blood or milk that the enzyme for synthesizing vitamin C in the young fetus or nursing pig is curtailed. Weaning seems to be the triggering mechanism or more precisely the cessation of an exogenous source of vitamin C to the young pig that stimulates the activity of the enzyme to produce vitamin C. This does not occur at 1 week of age, but rather at the age when the pig is weaned (Figure 4).

Because the pig does not synthesize adequate vitamin C at the time of weaning, we conducted an experiment to evaluate if the pig would respond to added dietary vitamin C and if it differed by time postweaning. The results in Table 3 demonstrated that there was indeed a growth response to vitamin C during the initial 10 day postweaning period but the growth response thereafter was minimal. It is during this early period postweaning where we would expect to see a growth response if one existed, for during the latter weeks postweaning the pig should now be capable of synthesizing an adequate amount of vitamin C.

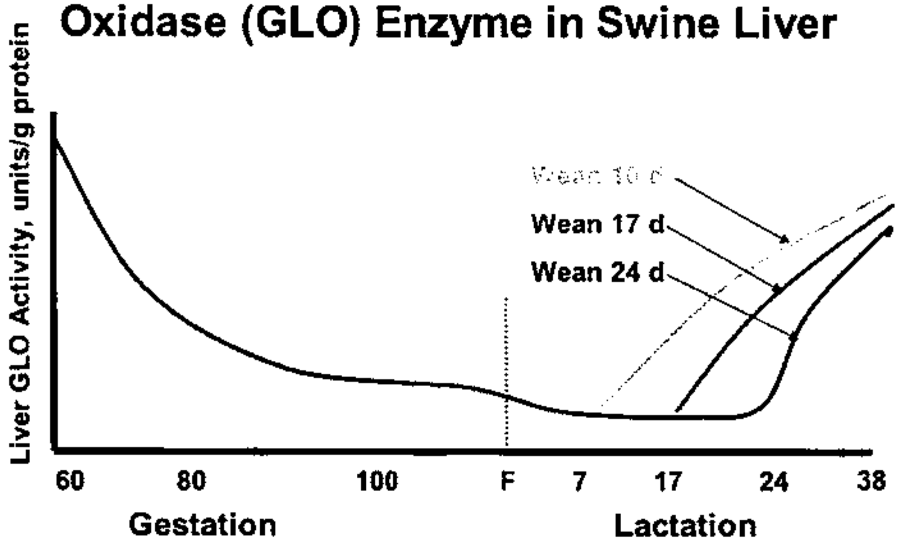
Because the levels used in the above experiment were substantially above that which might be added to normal nursery diets, we explored the effects of feeding lower levels of vitamin C to the weaned pig. In addition, we wanted to evaluate the effects at three different research stations (i.e., Purdue, Michigan State, and Ohio State). The dietary levels evaluated presented in Table 4 demonstrated that the overall response at the 3 research stations resulted in no growth response. However, in 2 of the 3 stations there was an apparent response with the effects being significant ($P < 0.05$) at only one station (Figure 5). When we further partitioned the weight of the pig into light or heavy weights at the time of weaning, there was no difference in growth response to the various vitamin C levels. These results demonstrated an inconsistent response to dietary vitamin C in weanling pig diets, but if a response occurs, it most like would occur during the early phases postweaning and perhaps under periods of animal stress.

One of the primary functions of vitamin C is to regenerate vitamin E so that it's active form can serve as an antioxidant in the body. An experiment conducted to evaluate the effects of vitamin C on serum α-tocopherol concentrations was conducted. The results showed such an affect at the 38 day postweaning period when increasing levels of vitamin C was fed (Figure 6), whereas earlier responses were not demonstrated.

Implications:

The antioxidant status of the weaned pig depends upon several nutrients, the main ones being vitamin E and selenium. Vitamin E status in the weaned pig can be improved by feeding the sow adequate vitamin E (i.e., 44-60 IU / kg diet). Adding dietary vitamin E to the nursery diets (40 to 60 IU/kg), and adding fat (5%) will increase serum and tissue α-tocopherol concentrations. The current high usage of vitamin A in many swine nursery feeds may be detrimental to the weaned pig by reducing the absorption of vitamin E and the tissue reserves of α-tocopherol. Added vitamin C had been shown to improve postweaning pig growth responses in many but not all cases. Vitamin C seems to improve the vitamin E

Figure 4. Pattern of Gulonolactone Oxidase (GLO) Enzyme in Swine Liver



Source: Ching et al. (2001a, b)

Figure 5. Effect of Dietary Vitamin C on Postweaning Pig Performance (0-24 d)

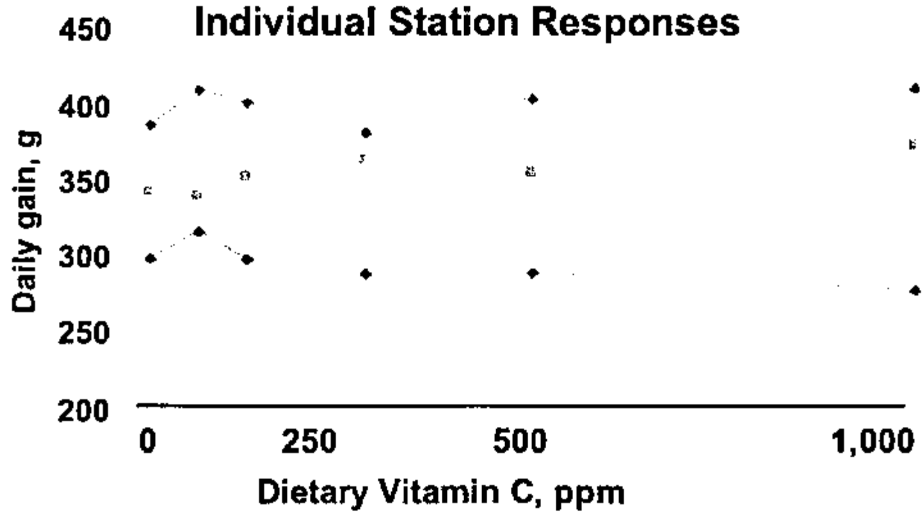


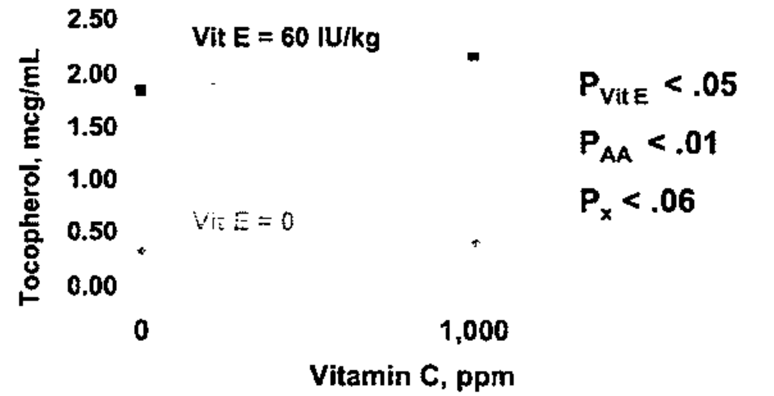
Table 3. Effects of Dietary Vitamin C Levels for Weaned Pigs.

	Vitamin C level, ppm				
Item	0	500	1,000	3,000	SEM
No. of pigs	65	65	65	65	-
Daily gain, g					
0-10 day	145	177	189	191	15[b]
10-24 day	385	369	386	389	21
24-38 day	617	636	626	635	19
Daily feed, g					
0-10 day	255	296	285	289	18
10-24 day	558	558	578	586	29
24-38 day	993	1,056	1,039	1,050	52
Gain:feed ratio, g/kg					
0-38 day	626	625	639	640	19

[a] A total of 260 pigs were weaned at 18 day of age and weighed an average 6.8 kg body weight at the start of the trial.

[b] $P < 0.05$

Figure 6. Effect of Dietary Vitamin C on Serum α-tocopherol (38 day)



status in the weaned pig by regenerating the vitamin E molecule to its active form. Our results suggest that vitamin E should be added to postweaning diets at 40 to 60 IU/kg, that nursery diets should contain added fat, and that vitamin C (stabilized form) be added at 150 ppm for at least the initial 28 day postweaning.

References cited:

Braude, R., S. K. Kon, and J. W. G. Porter. 1950. Studies in the vitamin C metabolism of the pig. Brit. J. Nutr. 4:186-199.

Ching, S., D. C. Mahan, J. S. Ottobre, and K. Dabrowski. 2002. Ascorbic acid synthesis in fetal and neonatal pigs and in pregnant and postpartum sows. J. Nutr. 131:1997-2001.

Ching, S., D. C. Mahan, and K. Dabrowski. 2002. Liver L-gulonolactone oxidase activity and tissue ascorbic acid concentrations in nursing pigs and the effect of various weaning ages. J. Nutr. 131: 2002-2006.

Ching, S., D.C. Mahan, T. G. Wiseman, and N.D. Fastinger. 2002. Evaluating the antioxidant status of weanling pigs fed dietary vitamins A and E. J. Anim. Sci (in press).

Coehlo, M. 2000. Poultry, swine, dairy vitamin supplementation up-dated. Feedstuffs July 3, p 12.

Moreira I., and D. C. Mahan. 2002. Effect of dietary levels of vitamin E (all-rac-tocopheryl acetate) with or without added fat on weanling pig performance and tissue α-tocopherol concentration. J. Anim. Sci. 80:663-669.

Table 4. Effect of Dietary Vitamin C Levels for Weaned Pigs at Three Research Stations

Item	Vitamin C, ppm							
	0	75	150	300	500	1,000	SEM	P < .xx
Overall Summary (3 Stations) [a]								
Daily gain, g								
0-10 day	211	210	220	209	216	217	8	ns[a]
10-24 day	477	494	485	483	486	494	9	ns
Station 1 [b]								
Daily gain, g								
0-10 day	176	179	208	188	199	211	13	.01
10-24 day	512	505	500	541	515	539	16	ns
Station 2 [c]								
Daily gain, g								
0-10 day	213	210	197	193	190	179	10	.01
10-24 day	386	425	403	386	392	379	12	ns
Station 3 [d]								
Daily gain, g								
0-10 day	244	271	255	247	260	262	17	ns
10-24 day	533	552	553	521	552	564	19	ns

[a] The overall summary included the three stations with a total of 85 pigs per treatment group with an average initial weight of 6.2 kg body weight.

[b] Station 1 used 30 pigs per treatment group with the pigs weighing an average initial body weight of 5.7 kg

[c] Station 2 used 35 pigs per treatment group with the pigs weighing an average initial body weight of 5.7 kg.

[d] Station 3 used 20 pigs per treatment group with the pigs weighing an average initial body weight of 6.6 kg.

High Levels of B-Vitamins -- Do They Help?

T.R. Cline and Brandon Hill, Department of Animal Sciences, Purdue University

Summary

Research results published from well replicated experiments to determine the value of adding high levels of B vitamins to pig diets are scarce. More has been done with weanling age pigs than with growing-finishing pigs. It is concluded that the NRC suggested requirement level (see table 2) supplemented to nursery diets is adequate to maximize growth performance.

Introduction

Although all of the B vitamins have been known for over 50 years, research interest continues. The preponderance of current research concerned with B vitamins revolves around molecular mechanisms of catalysis with particular emphasis on disease control and/or prevention. As would be expected, this work is aimed toward the human population. Vitamin research using pigs is not a crowded field, but there is some increased interest in the last 10 years. Suggestions have been made that modern pigs, with a higher lean accretion to gain ratio, may require higher levels of B vitamins. Limited research has been conducted to evaluate that possibility. On the other hand, there has been interest in deleting all vitamins from the later stages of the finishing diet in order to decrease the cost of production. A few laboratories have limited research data utilizing the practice, but those experiments will not be covered in this review. This presentation will focus on summarizing some of the recent research evaluating feeding high levels of B vitamins. Although little of the data is published in referred journals, the majority of the work has been conducted with weanling pigs.

Weanling Pigs

Wilson et al., (1992) were among the first researchers to suggest that weanling pigs might respond to levels of B vitamins considerably higher than those suggested by the NRC. They fed differing amounts of niacin, riboflavin, pantothenic acid and B12 at levels at least 10 times higher than "normally used in production" and reported significant improvements in both gain and feed conversion. These same workers (Wilson et al., 1993) failed to substantiate their earlier work and apparently did not pursue this avenue further.

Stahly et al., (1995) published an abstract which suggested that high lean gain pigs may require elevated levels of riboflavin, niacin, pantothenic acid, folacin and/or B12. They compared two genetic lines of pigs and reported that the high lean gaining line required in excess of 470% of the recommended NRC level of one or more of the above five vitamins. Using similarly designed experiments, Stahly and Cook (1996) indicated that pigs exposed to either a moderate or high level of antigen needed higher than NRC recommended levels of one or more of the five B vitamins (riboflavin, niacin, pantothenic acid, folacin, B12), but none of the pigs responded to the 470% NRC level as shown previously. Further work from the Iowa State lab (Lutz et al., 1999) suggests that responses noted above are, in all likelihood, not due to thiamin, folacin or niacin additions.

Woodworth et al., (2000) have published data to indicate that complex starter diets (corn-soybean meal-whey-plasma) are deficient in B6, but not thiamin. They indicate that these types of diets need approximately 3.3 mg of added B6 per kg of diet during the first two weeks after weaning. No response was observed from supplemental B6 from 14-35 days. There is evidence that B6 levels in starter diets affect riboflavin status of pigs (Matte et al., 1998), but levels that cause potential problems would be considered pharmacological (30 mg B6 per kg diet).

Contrary to previously cited work, a recent report from Kansas State (Real et al., 2001) suggests that newly weaned pigs respond to additional levels of niacin. They reported that the complex diets used may need as much as 55 mg niacin per kg diet, but the response did not appear to be uniform.

The North Central Regional Swine Nutrition Committee (NCR-42) recently completed a very extensive weanling pig experiment to determine if high levels of B vitamins are needed in starter diets (Cline et al., 2002). The basal diets are shown in table 1.

A mixture of eight B vitamins (niacin, riboflavin, pantothenic acid, B12, thiamin, biotin, folacin and B6) was supplemented at various levels. A diet which contained no supplemental B vitamins was fed as a negative control (0X). The other three diets contained NRC suggested requirements for the pig (X), or levels in excess of the NRC (2X and 4X). See Table 2 for the composition of the vitamin premix. A total of 760 pigs in 35 replications at eight stations were fed their diets ad libitum in meal form for a 35 day period. Response criteria calculations were made for phase 1 (2 weeks), phase 2 (3 weeks) and for the overall period of five weeks. Data are presented in tables 3, 4 and 5.

Table 1. Diet Composition, %

Ingredient	Phase 1	Phase 2
Corn	36.46	49.94
Soybean meal, 48% CP	22.84	23.47
Plasma protein	6.00	
Blood cells		2.00
Dried whey	20.00	20.00
Lactose	10.00	
Corn oil	1.00	1.00
Lysine-HCl	0.15	0.12
DL Methionine	0.11	0.09
Limestone	0.89	0.76
Dical	1.45	1.52
Salt	0.35	0.35
Trace mineral Premix	0.125	0.125
Selenium Premix	0.05	0.05
ADEK Premix	0.05	0.05
Zn0	0.28	0.28
Mecadox	0.25	0.25
B-vitamin Premix	Variable - replaced corn	

The data clearly show that the basal diet (0X) is deficient in one or more B vitamins, but that the 1X level of supplementation was sufficient to maintain pig performance responses. Much of the response noted above may be due to B12. Recent research reported from Nebraska (Blodgett et al., 2002) indicates that typical starter diets are deficient in B12, but not niacin.

Growing-Finishing Pigs

Very little research that deals with vitamin needs of growing-finishing pigs has been published in recent years. One can make the assumption that the change in genetics of today's pig may have affected needs for B vitamins, but no research has been published to substantiate that assumption. It has been standard practice for sometime to supplement corn-soybean meal diets with niacin, riboflavin, pantothenic acid and B12. The recommendation to not supplement these diets with B6, biotin, folacin or thiamin still appears sound. Easter et al., (1983)

Table 2. Recommended level of B vitamins (X)

Vitamin	Amount/kg feed
Biotin	.05 mg
Folacin	.30 mg
Niacin	18.11 mg
Pantothenic acid	11.24 mg
Riboflavin	3.83 mg
Thiamin	1.00 mg
B_6	1.83 mg
B_{12}	19.51 ug

Table 3. Average daily feed intake, g

Item	Phase 1	Phase 2	Overall
0X (Basal)	313[a]	840	629
1X	344	862	655
2X	323	865	648
4X	326	863	648

[a] Cubic effect, P = .003

Table 4. Average daily gain, g

Item	Phase 1	Phase 2	Overall
0X (Basal)	236	478[a]	381[a]
1X	250	536	421
2X	240	534	417
4X	246	525	413

[a] Quadratic effect, P < .01

Table 5. Gain/feed ratio, g/kg

Item	Phase 1	Phase 2	Overall
0X (Basal)	768	575[a]	611[b]
1X	741	626	647
2X	754	626	649
4X	765	612	640

[a] Quadratic, P < .01
[b] Quadratic, P < .02

failed to get a response to the addition of these four in growing-finishing diets.

It has often been assumed that many species of animals can and do get some B vitamins from the practice of coprophagy. De Passille et al., (1989) questioned if feces really serve as a source of nutrients for growing-finishing pigs. They measured fecal consumption on two different floor types at 10, 16 and 22 weeks of age. There was no affect of floor type on feces intake and almost no coprophagy in pigs from 16 or 22 weeks of age. Certainly, there was not a significant intake of B vitamins.

Virtually no data have been published to determine the effects of feeding high levels of B vitamins to growing-finishing pigs. Real et al. (2001) did report that they observed a slight improvement in feed conversion when niacin was added to grower finisher diets at a level of 55 mg/kg. A pharmacological level of niacin (550 mg/kg diet) produced slight improvements in drip loss, color and ultimate pH.

References Cited

Blodgett, S.S., P.S. Miller, A.J. Lewis, and R.L. Fisher. 2002. Response of weanling pigs to niacin and vitamin B12 supplementation. J. Anim. Sci. 80: (Midwest Section Abstr., p. 38).

Cline, T., S. Carter, G. Hill, S. Kim, A. Lewis, D. Mahan, H. Stein, and T. Veum. 2002. Supplemental B-vitamins in pig nursery diets. J. Anim. Sci. 80: (Midwest Section Abstr., p. 37).

De Passille, A.M.B., R.R. Bilodeau, C.L. Girard, and J.J. Matte. 1989. A study on the occurrence of coprophagy behavior and its relationship to B-vitamin status in growing-finishing pigs. Can. J. Anim. Sci. 69:299-306.

Easter, R.A., P.A. Anderson, E.J. Michel, and J.R. Corley. 1983. Response of gestating gilts and starter, grower and finisher swine to biotin, pyridoxine, folacin and thiamine additions to corn-soybean meal diets. Nutr. Reports Inter. 28:945-954.

Lutz, T.R., T.S. Stahly, D.R. Cook, and R.C. Ewan. 1999. Effects of dietary thiamin, folacin, or niacin regimen on growth in high lean pigs. J. Anim. Sci. 77 (Suppl. 1):189 (Abstr.).

Matte, J.J., C. Girard, and B. Sive. 1998. Vitamin B6 (pyridoxine) and vitamin B2 (riboflavin): Should we revise the requirements for early-weaned piglets? J. de la Recherche Porcine in France 30:253-257.

National Research Council. 1998. Nutrient Requirements of Swine, 10th Revised Edition. National Academy Press, Washington, D.C.

Real, D.E., J.L. Nelssen, M.D. Tokach, R.D. Goodband, S.S. Dritz, J.M. DeRouchey, B.W. James, and E. Alonso. 2001. Influence of dietary niacin on starter pig performance. Kansas State University Swine Day Report pp. 67-69.

Real, D.E., J.L. Nelssen, J.A. Unruh, M.D. Tokach, R.D. Goodband, S.S. Dritz, J.M. DeRouchey, and E. Alonso. 2001. Influence of increasing niacin on growth performance and carcass characteristics of grow-finish pigs reared in a commercial environment. Kansas State University Swine Day Report pp.105-110.

Stahly, T.S., and D.R. Cook. 1996. Dietary B vitamin needs of pigs with a moderate or high level of antigen exposure. J. Anim. Sci. 74 (Suppl. 1):170 (Abstr.).

Stahly, T.S., N.H. Williams, S.G. Swenson, and R.C. Ewan. 1995. Dietary B vitamin needs of high and moderate lean growth pigs fed from 9 to 28 kg body weight. J. Anim. Sci. 73 (Suppl. 1):193 (Abstr.).

Wilson, M.E., J.E. Pettigrew, G.C. Shurson, L.J. Johnston, H. Chester-Jones, and J.D. Jones. 1992. Effect of additional B vitamins in complex diets containing porcine plasma proteins and milk products or in simple diets on growth of weanling pigs. J. Anim. Sci. 70 (Suppl. 1):233 (Abstr.).

Wilson, M.E., M.D. Tokach, R.W. Walker, J.L. Nelssen, R.D. Goodhand, and J.E. Pettigrew. 1993. Influence of high levels of individual B vitamins on starter pig performance. J. Anim. Sci. 71 (Suppl. 1): 56 (Abstr.).

Woodworth, J.C., R.D. Goodband, J.L. Nelssen, M.D. Tokach, and R.E. Musser. 2000. Added dietary pyridoxine, but not thiamin, improves weanling pig growth performance. J. Anim. Sci. 78:88-93.

Nutrition and Pork Quality

Mike Ellis and Floyd McKeith, Professors
Department of Animal Sciences, University of Illinois, Urbana, IL 61801

Summary

There is increasing interest in nutritional approaches to improving pork quality defined in terms of color, water-holding capacity, palatability, and fat composition and consistency. In addition, there is potential to produce pork products with possible positive human health benefits using nutritional manipulation. This paper reviews a number of nutritional techniques that have been evaluated to improve pork color and water-holding including approaches to reduce the incidence of Dark, Firm, Dry pork (e.g., simple sugars), Pale, Soft, Exudative pig meat (e.g., magnesium, creatine monohydrate, etc.), and oxidative changes post mortem (e.g., vitamin E). In addition, the use of omega-3 fatty acids, conjugated linolenic acid, and selenium to produce pork with potential human health benefits is reviewed.

Introduction

Pork quality is a complex phenomenon with many components including nutritional, toxicological, technological, and sensory aspects. In addition, many quality attributes can be influenced by a multitude of factors that impact the animal from the farm through to slaughter. Also, postmortem factors can influence the quality of the meat at all stages through to consumption. Major quality issues of significant current concern and economic impact to slaughter industries worldwide include the color, water-holding capacity, and palatability of pork. Reduced water-holding in pork is a source of significant economic loss to the industry in terms of reduced saleable meat yields and color defects can lead to rejection of products by the consumer. Pork tenderness, juiciness, and flavor will ultimately determine the consumer's satisfaction and influence the future demand for pig meat. Another quality attribute that is receiving increasing attention relates to the quality and consistency of fat and, particularly, issues relating to soft fat. In addition, there is considerable interest in producing pork with attributes that have some health benefits to the consumer, although the specific attributes have not been clearly defined.

Historically, major improvements in quality attributes such as color and water-holding capacity have been achieved through changing the genetics of pigs, particularly selecting against mutations of genes with major negative effects on these traits, such as the Halothane and Rendement Napole genes. However, an increasing volume of research is being directed at the potential of nutrition to improve pork quality and this paper will review recent literature relating to the influence of nutrition on the quality attributes outlined above.

Pork Color and Water-holding Capacity

Major factors that are associated with variation in pork color and water-holding capacity are post-mortem changes in muscle pH and temperature, and oxidative changes in the muscle during storage. Post mortem oxidation in pork is of most concern when post mortem storage periods are extended such as when fresh products are exported.

After slaughter, glycolysis results in the conversion of muscle glycogen into lactic acid and a decline in muscle pH. Variation in the rate and/or the extent of post mortem glycolysis and, therefore, muscle pH decline is responsible for a major proportion of the variation in muscle color and water-holding capacity observed under commercial conditions. Pork with normal color and water-holding reaches an ultimate pH of 5.6 to 5.7 approximately 3 to 5 hours post mortem. There are three major pork quality conditions associated with color and water-holding that result from aberrations in pH decline as follows:

Pale, Soft, Exudative (PSE) pigmeat results from a very rapid decline in muscle pH when muscle temperatures are still high. The combination of relatively low pH (generally below 6.0 at 1 hour post mortem) and high temperature causes protein denaturation which results in pale pork color and a reduction in water-holding capacity.

Acid Pigmeat is produced when postmortem glycolysis is more extensive than normal, due to high muscle glycogen levels at slaughter (up to 80% higher) resulting in an abnormally low ultimate pH (generally in the range 5.2 to 5.4). In appearance, acid meat is very like PSE pork being both pale and having reduced water-holding capacity and these two conditions have often been confused in practice.

Dark, Firm, Dry (DFD) pigmeat is caused by a very limited postmortem decline in muscle pH, due to low muscle glycogen levels at slaughter, leading to a high ultimate pH in the muscle (generally ultimate pH values above 6.0 are associated with a high incidence of DFD). DFD meat has very good water-holding capacity with the water being tightly bound within the muscle structure. However, the high ultimate pH of DFD pork results in poor keeping quality, relatively rapid spoilage, and a relatively short shelf-life.

What should the industry target be for muscle pH? Obviously, the rapid and extensive drop in pH associated with PSE and the low ultimate pH of acid meat should be avoided as should the high ultimate pH associated with DFD. Thus, targets for ultimate pH in the longissimus are generally around 5.8. How can these targets be achieved? As previously discussed, pork quality attributes have multi-factorial causes and it is unlikely that one single factor, be it genetics or nutrition, will cure these problems. Rather, an integrated approach will be required where many factors from the farm through to slaughter and beyond will need to be optimized.

Nutritional Approaches to Improving Pork Color and Water-Holding Capacity

From a nutritional standpoint, what can be done to improve the color and water-holding of pork? The approach adopted will obviously depend on the problem being addressed and its primary causes.

Dark, Firm Dry Pigmeat: Historically this has not been a major economic problem in the US, however, recently there are reports of higher incidences of the DFD condition in commercial slaughter plants. It is not clear whether there has been a real increase in the incidence of DFD and if so what the major contributory factors to this increase might be. Increased transport distances from the farm to the abattoir with a consequent increase in time between last feed and slaughter may be involved. In addition, there has been an increased interest in holding pigs off feed prior to slaughter to reduce muscle glycogen levels and increase muscle ultimate pH and this practice can increase the incidence of DFD.

If DFD is a problem and given that it is caused by reduced muscle glycogen levels at slaughter the obvious solution to this problem is to provide energy to the animal sufficiently close to slaughter to increase and/or maintain normal muscle glycogen levels. This can be achieved by either reducing the time between the last feed and slaughter, or, in situations where the time between the animal leaving the farm and slaughter is extended, feeding during transport or in the lairage. In addition, feeding simple sugars prior to slaughter, which can be administered via the water supply in the lairage, can increase muscle glycogen levels and decrease the incidence of DFD.

Pale, Soft, Exudative Pigmeat: Based on the preceding discussion, approaches to reducing PSE should target one of the following.

- Reducing the rate of post mortem pH decline in the muscle
- Increasing ultimate pH either by limiting the extent of post mortem glycolysis or by buffering the muscle tissue
- Reducing muscle temperatures at slaughter and/or increasing the rate of carcass cooling as soon as possible after slaughter

This later approach involves a combination of pre-slaughter animal management and post-slaughter carcass chilling procedures and is outside of the scope of this paper.

A wide-range of nutritional approaches to reducing the incidence of PSE have been evaluated. For some, there is a relatively extensive literature, however, for many relatively few studies have been carried out. Generally speaking, results relating to the effect of any one nutrient on pork color and water-holding capacity have been variable and with many of these approaches further research is required to demonstrate efficacy, practical feasibility, and cost.

Magnesium: Feeding magnesium salts for a short period prior to slaughter has recently been investigated in a number of studies. A range of magnesium salts have been evaluated including aspartate, sulfate, chloride, and proteinate and all have shown efficacy for improving color and water-holding. Responses have been somewhat variable; early Australian research showed a consistent reduction in the incidence of PSE from pre-slaughter magnesium administration (D'Souza et al., 1998; 1999a,b,c). However, a number of studies carried out in the US and Canada (Schaefer et al., 1993; Caine et al., 2000) have shown a much smaller, less consistent effect. In studies carried out at the University of Illinois, we have shown a benefit of magnesium supplementation for improving pork color and water-holding capacity, although the results have been somewhat inconsistent with respect to the effect of dose level and time of administration (Hamilton et al., 2002). The most common dosage level tested has been 3.2g of elemental magnesium per pig per day and a feeding period of 5 days. However, in some studies lower levels (1.6g magnesium/pig/day) and shorter feeding period (1 to 2 days) have produced a response. Two potential mechanisms have been proposed for magnesium-mediated improvements in pork color and water-holding. Firstly, magnesium may reduce catecholamine (epinephrine and norepinephrine) release and, consequently, limit the glycolytic response to pre-slaughter stress. In addition, it has been proposed that magnesium may antagonize calcium within the muscle, thus reducing calcium stimulated muscle contractions and thereby reducing the rate of postmortem glycoylsis.

Creatine Monhydrate: It has been proposed that creatine monhydrate can bind phosphate within the muscle thus increasing its buffering capacity and reducing the rate and extent of post-mortem muscle pH decline. In one experiment (Berg et al., 1999), feeding creatine monhydrate for 5 or 10 days prior to slaughter increased the ultimate pH in the semimembranosus but not the longissimus and tended to reduce drip loss. Maddock et al. (2000) reported the feeding creatine monohydrate for 5 days had no effect on objective muscle color, however, the percentage of PSE was reduced from 75% to 30% in the longissimus and from 68% to 38% in the semimembranosus. In a review, Berg et al. (2000) summarized experiments that fed between 20 and 25 g/pig/day of creatine monhydrate for between 5 and 15 days prior to slaughter and concluded that "the effects .... appear to be variable regarding pork quality".

Other Compounds: A range of other dietary compounds have been evaluated at the research level for their effectiveness in improving muscle color and water-holding capacity. These include chromium, conjugated linoleic acid, betaine, reduced starch levels, sodium oxalate, vitamin C, vitamin D3, quercetin, electrolytes, tryptophan, chromium, and carnitine. Generally speaking, the responses to these compounds have been variable and inconsistent.

Post Mortem Oxidative Changes in Pork

Lipid oxidation is potentially a major cause of detrimental changes in pork during storage that has been associated with deterioration in muscle color, increased oxidative rancidity, and associated increase in off flavors in the meat, and reduced shelf life. This reduction in shelf life is of critical importance in products that are exported because of the extended time from slaughter to consumption of the meat. In addition, it has been suggested that oxidation of the lipids within the cell membranes can reduce membrane integrity and increase drip loss from the muscle.

Vitamin E: The most widely researched antioxidant in farm livestock is vitamin E and there is a volume of literature relating to the effects of feeding supra-nutritional levels of α-tocopherol to pigs prior to slaughter on postmortem oxidative changes in pork. Recommendations for dietary requirements for α-tocopherol are around 11 mg/kg (NRC, 1998), although, higher levels (30 mg/kg or above) are recommended in situations where relatively high levels of unsaturated fats are fed. The impact of feeding high vitamin E levels on pork quality has been reviewed by a number of authors (e.g., Pettigrew and Esnaola, 2000). Levels evaluated have generally been in the range of 100 to 800 mg/kg of feed of DL-α-tocopherol and feeding durations have been in the range of 42 days upwards to 6 months. The majority of studies showed a dose-dependent increase in muscle vitamin E levels and a reduction in lipid oxidation during storage. Responses in muscle color and water-holding have been more variable. A number of studies have shown that supra-nutritional levels of vitamin E can preserve muscle redness (generally measured as a* values) and a few studies have shown a reduction in drip loss as a result of vitamin E supplementation. Practical recommendations for use of vitamin E to improve pork quality are to feed 200 mg/kg of

"-tocopherol for at least 6 weeks prior to slaughter, although these are based as much on economics as on efficacy.

Producing Healthy Pork

Concerns over the health risk associated with the consumption of fats, particularly saturated fats of animal origin has led some to suggest a reduction in meat consumption. An alternative approach is to reduce the amount and modify the composition of pork fat so that is more in line with the recommendations for a healthy diet.

The swine industry has been particularly successful at reducing the fat content of pork largely through a combination of improvements in genetics and nutrition. This has been achieved against a background of substantial increases in slaughter weight in most countries. For example, in the US over the last 10 years or so average backfat thickness levels have been reduced from in excess of 25 mm to a level of around 15 to 17 mm while slaughter weights have increased from around 105 to 120 kg and in the UK, where slaughter weights are relatively low and entire males are used, average backfat thickness levels are 10 to 11 mm.

In addition, a number of meat processors and retailers have developed lines of low fat/high lean/ healthy pork products. For example, the total and saturated fat contents of one line of lean pork cuts was approximately half of those for typical commercial cuts. However, the option also exists to modify the composition of the fat in the carcass to produce a "healthier" product

Fat Composition in Pigs

Interest in manipulating the composition of fat in pigs stems from three issues:

- concerns over the quality of fat, defined in terms of fat softness/firmness and oxidative stability
- opportunities to improve the health benefits of pork for the consumer
- interest in improving pork eating quality

Unfortunately, these aspects are often conflicting - improving the health benefits of pork may result in a product with soft fat that develops oxidative rancidity relatively quickly. There is, thus, some disagreement over what is the ideal fatty acid profile for pork.

The considerable improvements in carcass leanness that have been achieved over recent years have been accompanied by reductions in intramuscular fat (IMF) or marbling. In the US, we now have pigs with less than 2% IMF on average and some lines have IMF levels of 1% or less are common.

These changes in the level of IMF have been accompanied by changes in the fatty acid profile of fat. Leaner pigs have a higher concentration of unsaturated fatty acids (particularly linoleic and linolenic) in the fat and this generally results in a softer fat tissue. From the standpoint of dietary manipulations of fatty acid composition, lean pigs have the advantage that a greater proportion of their fat is derived from dietary fat sources, with a correspondingly smaller proportion from de novo synthesis. Thus, leaner pigs are more responsive to dietary manipulation of fat composition than fatter animals. However, the low IMF levels may limit the impact of any treatment on aspects such as eating quality. There are approaches to increasing IMF content that can be used by producers, such as using genotypes with increased IMF and feeding low protein/high leucine diets in the few weeks prior to slaughter, however, these approaches can also increase production costs.

Another issue is the relative effects of dietary fat composition on the fatty acid profile of the different fat depots. Most research has focused on subcutaneous fat and there is a good understanding of the relationship between dietary fatty acid profile and that in the subcutaneous fat. However, the relationship between the fatty acid profile of the diet and the composition of the IMF is not as well established.

Omega-3 Fatty Acids

Omega-3 fatty acids are claimed to be beneficial in preventing cardiovascular disease and are essential nutrients for pigs that are required for brain and retinal development and function.

A precursor on n-3 polyunsaturated fatty acids is linolenic acid which in normal backfat and muscle is present at about 1% of the total fatty acids. This level can be increased using dietary fat sources high in linoleic, particularly linseed, flaxseed, and fish oil (Riley et al., 1998a,b). Fish oil is normally not used because of potential problems with fish taints in the pork. However, a number of studies have shown an increase in lipid oxidation and increase in off-flavors in meat products containing high linolenic acid levels, particularly for processed and cured products. In some, but not all studies, feeding high levels of dietary antioxidants such as vitamin E has been effective in reducing off flavors associated with lipid oxidation. In addition, there is limited data on the impact of high linolenic levels in fat tissue on fat firmness and processing characteristics although this is likely to be negative.

Conjugated Linolenic Acid

Conjugated linoleic acid (CLA) is a series of positional and geometric isomers of linoleic acid which have several effects in the animal. Of particular interest in humans is the anticarcinogenic properties of CLA which has prompted an increased interest in producing animal products with enhanced CLA concentrations. Another effect is the improvement in carcass leanness when CLA is fed to pigs that has been observed in a number, but not all studies. Variation in response may well reflect, in part at least, the specific isomer composition of the CLA product. Modified tall oil, a by-product of the wood pulp industry, is a source of CLA that has been used in studies and, in addition, there are some manufactured sources now available. Interestingly, although CLA reduces carcass fat it has been shown in a number of studies to increase intramuscular or marbling fat. In addition, CLA has also been found to increase fat and belly firmness via a shift in the fatty acid profile of body fat from unsaturated to saturated. Conjugated linoleic acid may, therefore, be used to counteract the negative effect of dietary unsaturated fats on fat firmness. However, feeding CLA to pigs has been found to have no effect on the oxidative stability of the fat. There are reports of improvements in pork color and water-holding capacity in CLA fed pigs, although this result has not been consistent. Dose levels for CLA used in studies have generally been in the range of 0 to 1% of the diet and at the highest dose level the concentration of CLA has been up to around 2% in subcutaneous fat and 0.3 to 0.4% in lean tissue.

Selenium

There is evidence in humans that selenium is anticarcinogenic and reduces the risk of certain cancers when given as a daily supplement at relatively high levels. In theory, therefore, it is feasible to produce high selenium pork products by supplementing diets with selenium. In practice, however, the dose of dietary selenium necessary to increase the selenium content of pork to levels high enough to prevent cancers in humans has not been established and care needs to be taken not to exceed dietary levels that will produce a toxic effect.

References

Berg, E.P., Spenser, J.D., and Allee, G.L. 1999. Dietary supplementation of creatine monohydrate in swine finishing diets improving pork quality. Journal of Animal Science. 77:(Supplement l):46 (Abstract).

Berg, E.P., Linville, M.K., Stahl, C.A., Maddock, K.R., and Allee, G.L. 2000. Does creatine monohydrate supplemented to swine finishing rations effect pork quality. 53rd Annual Reciprocal Meat Conference. Page 124.

Caine, W.R., Schaefer, A.L., Aalhus, J.L.and Duga, M.E.R. 2000. Behaviour, growth performance and pork quality of pigs differing in porcine stress syndrome genotype receiving dietary magnesium aspartate hydrochloride. Canadian Journal of Animal Science. 80:175-182.

D'Souza, D.N., Warner, R.D., Leury, B.J. and Dunshea, F.R. 1998. The effect of dietary magnesium aspartate supplementation on pork quality. Journal of Animal Science. 76:104-109.

D'Souza, D.N., Warner, R.D., Dunshea, F.R., and Leury, B.J. 1999a. Comparison of different dietary magnesium supplements on pork quality. Meat Science. 31:221-225.

D'Souza, D.N., Warner, R.D., Leury, B.J., and Dunshea, F.R. 1999b. Effect of dietary magnesium supplementation and mixing boars during lairage on pork quality. Manipulating Pork Production VII. P185.

D'Souza, D.N., Warner, R.D., Leury, B.J., and Dunshea, F.R. 1999c. Dietary magnesium supplementation improves pork quality. Manipulating Pig Production VII. P184.

Hamilton, D.N., Ellis, M., Hemann, M.D., McKeith, F.K., Miller, K.D., and Purser, K. 2002. The impact of Rendement Napole genotype and short-term feeding of magnesium sulfate hetahydrate prior to slaughter on carcass characteristics and pork quality. Journal of Animal Science .. 80:1586-1592.

Maddock, R.J., Bidner, B.S., Carr, S.N., McKeith, F.K., Berg, E.P., and Sewell, J.W. 2000. Supplementation with creatine monohydrate improved the lean quality of fresh pork of two different genotypes. 53rd Annual Reciprocal Meat Conference. p 118.

NRC. 1998. Nutrient Requirements of Swine. 10th Ed. National Academy Press, Washington, DC.

Pettigrew, J.E., and Esnaola, M.A. 2000. Swine Nutrition and Pork Quality. National Pork Producers Council, Des Moines, IA.

Schaefer, A.L., Murray, A.C., Tong, A.K.W., Jones, S.D.M., and Sather, A.P. 1993. The effect of ante mortem electrolyte therapy on animal physiology and meat quality in pigs segregating at the halothane gene. Canadian Journal of Animal Science. 73:231-240.

Effects of HACCP Regulations in the Feed Manufacturing Business

Wesley N. Osburn
Assistant Professor
Department of Animal Science
Michigan State University
East Lansing, MI 48842

Summary

The Hazard Analysis Critical Control Point (HACCP) system is a federally mandated food safety program for meat and poultry plants inspected by the United States Department of Agriculture Food Safety Inspection Service (USDA-FSIS), and for seafood processing plants inspected by the Food and Drug Administration (FDA). Current regulations do not mandate that feed manufacturing businesses implement HACCP if they desire to produce products for animal consumption. However, the importance of food safety to the public and governmental agencies has resulted in food and feed manufacturers voluntarily applying the principles of HACCP for feed production systems.

Successful implementation of a HACCP-based food safety system for feed manufacturers requires the establishment of effective prerequisite programs: good manufacturing practices (GMPs) and standard operating principles (SOPs). Feed mills that operate according to these prerequisite programs or other quality assurance programs will find the transition to a HACCP-based food program to be less complicated. Although these prerequisite and quality assurance programs work in conjunction with HACCP principles to enhance food safety, they are more directed toward *product quality and wholesomeness.* HACCP is focused on *product safety.*

Food safety is enhanced by conducting a risk (hazard) analysis, identifying critical control points (CCPs) in the process, setting critical limits for the CCPs, monitoring them, taking corrective action when necessary, maintaining accurate records and conducting verification activities. Proper implementation of HACCP in feed mill operations will ensure that the feed produced is safe for animal consumption and the documentation is available to prove that these products were produced safely.

Introduction

The Hazard Analysis Critical Control Point (HACCP) system is based on the application of scientific principles to prevent, eliminate or reduce biological, physical or chemical hazards to an acceptable level so that food products can be safely produced for human or animal consumption. HACCP principles may be applied to pre- and post-harvest food manufacture, distribution, foodservice, retail and consumer segments. HACCP was used by Pillsbury to ensure safe food for astronauts during the 1960's NASA space program and is widely recognized as an effective science-based system to enhance food safety. Currently, HACCP is mandated in all federally inspected meat and poultry plants (USDA-FSIS) and seafood processing plants (FDA). Although the federal mandate for HACCP implementation occurred in the "middle" of the meat animal production chain, there is no question that that the impetus for HACCP implementation will continue toward both "ends" of the chain - from "on the farm" to feedlots, through the processing sectors and on to foodservice and retail sectors.

The following is a brief overview of the seven principles of HACCP:

1. Conduct a hazard analysis. Identify potential hazards (biological, chemical or physical) that could occur in the food production process.
2. Identify the critical control points (CCPs). These are points in the process where hazards of significance exist and are reasonably likely to occur. Failure to apply critical control points at these steps may result in a significant hazard.

3. Establish critical limits for preventive measures associated with each CCP.
4. Monitor each CCP to ensure that the limits are not exceeded.
5. Take corrective action when monitoring determines that a CCP is not within the established critical limits.
6. Establish verification procedures (other than monitoring) that determine the validity of the HACCP system to ensure it is working properly.
7. Establish record-keeping and documentation procedures that the HACCP system is being monitored and working correctly. It is important to document (prove) that the food product is being produced in a safe manner.

My assignment is to address the effects of HACCP regulations on the feed manufacturing business. This paper will provide information to stimulate discussion on how feed manufacturers can successfully integrate a HACCP-based food safety system into current existing production processes.

Management Commitment to HACCP

Successful implementation of federal food safety regulations (i.e. HACCP programs), first requires feed manufacturers to thoroughly understand all aspects of their production and processing system(s), suppliers and vendors, personnel and equipment, training programs and their customers. A key component to the success of incorporating federal food safety regulations into an existing feed manufacturing business is upper management's commitment to food safety and the principles of HACCP. Without management's commitment and support, development and implementation of a HACCP program will not likely succeed. In fact, a poorly developed and resourced HACCP program may provide a false sense of security and could potentially be worse that having no HACCP program at all (Jones and Ricke, 1994).

Another key point to recognize is that one single HACCP plan cannot cover all the feed mills operated by a feed manufacturer. Each feed mill has unique layouts, equipment, operating procedures, products and personnel that require a HACCP plan to be developed for each separate feed mill facility. Because the implementation of a HACCP system will be an integral part of a feed manufacturer's operating system and will require major investments in time , money and other resources, it is imperative that management commitment and program accountability be established prior to the beginning of HACCP plan development (Jones and Ricke, 1994)

One food safety expert has estimated that it may take from six months to as long as three years to implement a successful HACCP program (Stier, 1992). The development of an interdisciplinary HACCP team composed of personnel from all areas of feed mill operations (quality assurance, marketing, production, maintenance, etc.) led by a HACCP coordinator who has overall responsibility for the organization and management of the HACCP program is vital to successful implementation of HACCP. After the team is appointed, they will plan, develop and implement the HACCP program which requires the collection of scientific, regulatory, and production informational that has a direct impact on food safety (National Food Processors Association (NFPA), 1999). This background information provides essential details for the proper application of HACCP principles. If a feed manufacturer wishes to voluntarily implement HACCP, the management team must buy in to a long-term commitment of resources or the HACCP program may likely fail.

Prerequisite Programs

Before HACCP can be successfully implemented a feed manufacturing facility must have established support programs termed "prerequisite programs." These programs provide basic environmental and operating conditions that are necessary for the production of safe wholesome of human food or animal feed. Many of these guidelines are provided in various federal, state and local regulations. Two primary prerequisite programs for meat and poultry processing facilities are Good Manufacturing Practices (GMPs) and Sanitation Standard Operating Procedures (SSOPs). In meat and poultry plants, USDA-FSIS mandates that no plant can develop and implement a HACCP plan until an effective SSOP has been established.

I am sure that many feed manufacturers have established GMPs and standard operating procedures (SOPs) for various operations within their facilities. A total quality management program (TQM) may also be established. It is important to emphasize at this point that these programs tend to focus directly on product *quality* and less on product *safety*. HACCP is a preventive system that focuses entirely on food safety by identifying and assessing biological, chemical and physical hazards and implementing preventive measures (CCPs) that prevent, eliminate or reduce a hazard to an acceptable level. However, feed manufacturing sites that have some type of quality assurance program in place will find that these programs can help the plant transition into a HACCP-based program. Quality assurance programs that assist in the production of safe products by existing process controls may be beneficial in helping a feed manufacturer adjust to a HACCP-based system (McChesney, 1996). HACCP is not intended to replace effective quality assurance programs, however, the integration of prerequisite programs (GMPs, SSOPs and SOPs) along with an effective TQM program will allow feed manufacturer's to utilize HACCP to focus directly on issues that impact product safety.

Good Manufacturing Practices

Good manufacturing practices (GMPs) are effective for the production of wholesome human food and animal feed. These practices are found in Title 21 of the Code of Federal Regulations (CFR) Section 402(a)(4) of the Food, Drug and Cosmetic Act of 1938 provides specific definitions for adulterated foods which can be addressed by GMPs. Some examples of adulterated foods are:

a. contains poisons or harmful substances at detrimental concentrations
b. contains filth or is decomposed
c. was prepared or handled under unsanitary conditions
d. is derived from a diseased animal

These definitions provide the legal basis for sanitation requirements established in GMPs. These general guidelines include regulations for basic rules for sanitation, in a food establishment, personal hygiene, maintenance of physical facilities, cleaning and sanitizing of equipment, storage and handling of equipment, pest control and the use and storage of cleaning compounds, sanitizers and pesticides (Lobo, 2000). Other documents provide additional information on GMPs for feed manufacturers. The regulations prescribing good manufacturing practices for Type B and Type C medicated feeds can be found in the Code of Federal Regulations (CFR, 2000). The Food and Agriculture Organization (FAO 1997) provides a draft code of GMPs for good animal feeding in a report of an FAO expert consultation on animal feeding and food safety.

Although GMPs provide food safety basics, it is recognized that GMPs are too broad to address plant- or product-specific hazards, all GMPs are considered to have the same value and no consideration is given as to whether non-compliance poses an unacceptable health risk. Finally GMPs do not require record keeping, monitoring or controls, establishing critical limits or corrective actions. However, plants that have written GMPs and have trained their employees to follow them understand the importance of basic sanitation requirements and will be able to implement HACCP more easily.

Sanitation Standard Operating Procedures

As part of the "Mega-Reg" (USDA-FSIS, 1996) USDA-FSIS requires all meat and poultry plants to develop, maintain and adhere to written sanitation standard operating procedures (SSOPs) based on the belief that effective sanitation is critical for food safety and proper implementation of a HACCP program. The SSOPs for meat and poultry plants are mandated by USDA-FSIS (CFR, 1999). The regulations require official meat and poultry establishments to develop, implement and maintain written SSOPs which include:

a. a description of the procedures to be conducted daily, before and during operations and how they will be monitored for compliance
b. identification of the individual with overall authority for to implement and maintain the SSOP
c. a description of pre-operational sanitation tasks to be conducted
d. the frequency with which each procedure in the SSOP will be conducted (NFPA, 1999)

Inadequate sanitation is a concern for feed mill operations. Development of an SSOP for feed mill operations would help improve sanitation in the following areas: personal hygiene, maintenance of facilities and grounds, sanitary facilities and controls, production processes and employee training (McChesney, 1996).

Prerequisite program or HACCP?

The importance of prerequisite programs is realized when determining whether a potential hazard (biological, chemical or physical) can be controlled by GMPs or SSOPs, or if it is of such significance (based the hazard's likelihood of occurrence and its severity) that it must be addressed in the HACCP plan. Significant hazards that are reasonably likely to occur at a point in the production process may be designated as a CCP, which then requires the establishment of critical limits, monitoring activities, corrective actions, record keeping and verification. Prerequisite programs assist in keeping the HACCP plan focused on significant hazards that if not controlled may result in a direct food safety threat to consumers of the product (animal or human) hazard. This allows the feed mill to monitor and keep records solely on those points in the production process that are designated as a CCP, rather than monitoring all steps in the production process for potential food safety hazards. This approach results in valuable plant resources (time, money, equipment, personnel) to be used solely on those steps where preventive measures (control) must be applied to prevent, eliminate, or reduce a hazard to an acceptable level.

Regulatory Compliance and HACCP

The feed manufacturing business must comply with the directives and regulations established in the Official Publication of the Association of American Feed Control Officials (AAFCO), in addition to any other appropriate federal, state or local statutes. Similarly, the meat and poultry industry must comply with guidelines and regulations contained in federal and/or state the meat and poultry inspection documents. The AAFCO Model National Medicated Feed Program addresses licensed ad non-licensed medicated feed manufacturing establishments and covers current GMPs, types of inspections, reports, education and training, and enforcement. A voluntary self-inspection pilot program (VSIP) was recently completed with approximately 150 medicated feed manufacturing facilities participating (AAFCO, 2002). It is important to note that although this program is directed toward food safety, it primarily addresses chemical (drug) hazards. A complete HACCP program would also address biological and physical hazards as well.

There can be a difference between regulatory compliance and food safety. For example, if a batch of pig grow-finishing diet is labeled as containing 10% crude protein, when in fact it contains 8%, this may not be considered a food safety issue but rather a regulatory compliance (truth in labeling) issue. However, if this batch of feed contains an unapproved drug, then there is a food safety issue (chemical hazard) that may harm the animals that consume the feed and could potentially harm the person(s) who consume the meat from these animals (drug residues). Another regulatory compliance issue may be improper labeling format. All the required information may be correctly listed on the label, but if it does not conform to established regulatory standards the label (and the product that is improperly labeled) is out of compliance. Generally speaking, an improper labeling format in this scenario may not indicate a direct food safety hazard.

Benefits of HACCP

HACCP is a preventive system designed to prevent significant hazards (biological, chemical, physical) from occurring. Within this framework, the feed mill must conduct a hazard analysis (risk assessment), identify critical control points, establish critical limits and monitoring procedures, develop corrective actions, maintain an effective record keeping system and conduct verification activities to validate that the HACCP system is functioning properly. In order to accomplish these tasks, the feed industry and more specifically an individual feed mill, must continuously assess the effectiveness of its HACCP plan. Implementation of HACCP will ensure that the feed produced is safe for animal consumption and the documentation is available to prove that these products were produced safely in cases of litigation involving product recalls due to uncontrolled biological, physical or chemical hazards.

Currently, FDA conducts unscheduled and unannounced inspections; therefore, adoption of a HACCP-based system for food safety creates a deterrent value in the system (McChesney, 1996). Additionally, maintaining an effective record keeping system assists inspectors in verifying that the feed mill HACCP plan is working as intended to ensure that safe feed is being produced, rather than relying solely on plant inspections or end-product sampling.

Implementing HACCP does raise questions. If a feed manufacturing establishment already complies with GMPs and SOPs one might ask if implementing HACCP is a duplication of current efforts. McChesney (1996) addressed this point by envisioning HACCP as the mechanism by which industry feed safety programs can be merged, unified or eliminated so that all hazards associated with the production of a specific product are addressed. Another key point made was that the freedom one has in merging various food safety programs is dependent upon whether HACCP is mandatory or voluntary. Another question addressed by McChesney (1996) concerned what a feed mill would do differently if it adopted HACCP. The response was that there may be an increase in efficiency and an improvement in its record keeping system which would prove to be beneficial during inspections as well as addressing all hazards associated with the product(s) that are produced at that facility.

HACCP will require an investment of resources. Education and training are critical in successfully implementing a HACCP program. Many HACCP consulting companies are available who provide specific food safety training in HACCP principles. Professional organizations, often in conjunction with universities, can also provide feed manufacturers with HACCP training. It is important to reemphasize that a feed mill cannot implement HACCP overnight. It is a long-term commitment.

Perhaps the most significant benefit of incorporating HACCP is that feed manufacturer customers are asking for it, and the public demands it. Whether HACCP is mandated or voluntarily adopted, an effective feed mill HACCP plan will increase consumer confidence and trust that the meat they consume is from animal s that have been fed properly with no unapproved drugs or illegal ingredients (animal proteins).

Implications

The public demands food safety throughout the meat animal production chain. Whether mandated or voluntary adopted, the application of HACCP principles to the feed manufacturing industry will help ensure the production of safe products and assists feed mill establishments in documenting that feed products were produced in a safe manner. Several associations such as the National Grain and Feed Association and the American Feed Industry Association have published quality assurance programs based on GMPs and incorporated basic HACCP plan principles.

The current emphasis on food safety will not abate in the future. Voluntary adoption of HACCP will result in increased production efficiency, enhanced product safety and improved record keeping and documentation. The establishment of effective prerequisite programs is the first step toward implementing a HACCP-based food safety program. Following the basic HACCP principles of hazard analysis, identification of critical control points, establishing critical limits and monitoring activities, development of corrective actions, effective record keeping and conducting verification activities minimizes the opportunity for a feed mill to become involved in a potential foodborne illness outbreak that may result in expensive product recalls and unwanted press

References cited

AAFCO. 2002 AAFCO model national medicated feed program. Available: http://www.aafco.org/Mnmfp15.htm. Accessed July 5, 2002.

CFR. 1999. Title 9, Code of Federal Regulations, Part 308. sections 225.1-225.202. U.S. Government Printing Office, Washington, DC (Issued annually).

CFR. 2000. Title 21, Code of Federal Regulations, Part 225, sections 225.1-225.202. U.S. Government Printing Office, Washington, DC (Issued annually).

FAO. 1997. Animal feeding and food safety – Report of an FAO expert consultation. Available: http://www.fao.org/es/esn/animal/animalpdf/content.htm. Accessed Jul 5, 2002.

Jones F.T. and S.C. Ricke. 1994. Researchers propose tentative HACCP plan for feed mills. Pages 32, 36-37, 40-42 in Feedstuffs. May 2.

Lobo, P. 2000. Implementing GMPs and HACCP in the mill to improve feed safety. Feed Management , Jan 2000, Vol 51, Number 1, pp 27-28, 30.

McChesney, D.G. 1996. HACCP and the feed industry: Direction for the future? Arkansas Nutrition Conference, Center of Excellence for Poultry Science, University of Arkansas, Sept. 10-12, Fayetteville AR, pp-57-65.

NFPA. 1999. National Food Processors Association. HACCP: A Systematic Approach to Food Safety. Stevenson, K.E. and D.T. Bernard eds. The Food Processors Institute, Washington, DC.

R. Stier. 1992. Practical applications of HACCP. Pages 126-167 in HACCP Principles and Applications. Pierson, M.D. and D.A. Cortlett, eds. Van Nostrand Reinhold, New York, pp.

USDA-FSIS. 1996. United States Department of Agriculture Food Safety Inspection Service. Pathogen reduction: Hazard analysis and critical control point (HACCP) systems: Final rule. Federal Register 61 (144) 388806 (July 25).

Overview of Proposed Federal Environmental Regulations for Concentrated Animal Feeding Operations

Richard Coffey, Associate Extension Professor, Department of Animal Sciences, University of Kentucky, Research & Education Center, Princeton, KY 42445

Summary

Changes in the livestock and poultry industries, along with societal concerns of the effects of modern livestock and poultry production on the environment, have prompted the U.S. Environmental Protection Agency (EPA) to propose revisions to the regulations (*National Pollutant Discharge Elimination System Permit Regulation and Effluent Limitations Guidelines and Standards for Concentrated Animal Feeding Operations*) for concentrated animal feeding operations (CAFOs). The proposed regulations establish which operations will be defined or designated as CAFOs and describe the new permitting conditions for CAFOs. The proposed revisions also establish effluent limitations guidelines and limitations (ELGs) to control discharges of pollutants from CAFOs, which will be based primarily on technology requirements that will be implemented through the CAFOs' site-specific permit nutrient plan (PNP). Additionally, the proposed regulations set forth the monitoring, reporting, and record-keeping activities that will be required of CAFOs. Operations potentially subject to all or portions of the proposed regulations include those that confine beef cattle, dairy cattle (cows or heifers), veal, swine weighing over 50 lb, immature swine weighing less than 50 lb, broilers and layers (regardless of watering or manure handling system) , turkeys, ducks, horses, and sheep and lambs.

Introduction

The livestock and poultry industries have undergone substantial changes since the existing regulations for concentrated animal feeding operations (CAFOs) were issued in the mid 1970's. Since that time, there has been a growing trend towards fewer but larger operations, and greater emphasis on specialized production units and more intensive production practices. This has resulted in a larger concentration of manure and manure nutrients on individual farms and in certain geographic regions of the U.S., and has led some to question whether adequate land is available to accommodate the nutrient load from manure applications. Additionally, there have been a few, well publicized, unintentional discharges from CAFOs that have caused many in society to question the environmental integrity of large scale livestock and poultry production. Taken together, these changes and environmental issues have prompted several state and federal regulatory agencies to review and propose changes to existing environmental regulations.

The U.S. Environmental Protection Agency (EPA) has proposed revisions to the *National Pollutant Discharge Elimination System* (NPDES) *Permit Regulation and Effluent Limitations Guidelines and Standards* (ELGs) *for Concentrated Animal Feeding Operations* (2001). The proposed revisions to these regulations have already undergone the public commenting period, and are scheduled to be finalized in December, 2002. Once finalized, these regulations will provide the minimum regulatory action that all states will be required to meet. It is important to note that individual states have the latitude to enact regulations that are stricter than those being proposed by EPA. The EPA Office of Wastewater Management (2001) has compiled environmental regulations and programs for each state, and that publication can be consulted to view details of a particular state's current environmental regulations.

Although there are numerous proposed revisions to the current CAFO regulations, a majority of the proposed changes relate to the types of animal operations that are regulated, how animal feeding operations (AFOs) and CAFOs are defined, NPDES permit requirements for CAFOs, and technology requirements for CAFOs to meet changes to the effluent guidelines. This paper will provide an overview of some key proposed revisions in these areas.

Types of Animal Operations Regulated

Under the existing CAFO regulation, the following animal types were defined as CAFOs if the threshold number of confined animals shown was exceeded: 1,000 beef cattle; 700 dairy cows; 290,000 broiler chickens (if continuous overflow watering or liquid manure handling systems were used); 180,000 laying hens (if continuous overflow watering or liquid manure handling systems were used); 55,000 turkeys; 4,500 slaughter hogs; 35,000 feeder pigs; 12,000 sheep or lambs; and 145,000 ducks. Not included in this regulation were poultry operations that use dry manure handling or specialized swine operations such as stand alone nurseries.

To provide a more inclusive regulation, EPA is proposing revisions that would include the following categories of animal types that could potentially be classified as CAFOs:

- Cattle (excluding mature dairy or veal) – any age animal confined at a beef operation, including heifers when confined apart from the dairy. Also includes stand alone heifer operations.
- Mature dairy cattle – only mature cows, whether milking or dry, are counted to determine whether the dairy is a CAFO. Once determined to be a CAFO, all animals confined at the operation would be subject to the proposed CAFO requirements.
- Veal – all veal cattle, regardless of age or size, are counted to determine whether the operation is a CAFO.
- Swine weighing over 55 lb – only mature swine are counted to determine whether the operation is a CAFO. Once determined to be a CAFO, all animals confined at the operation would be subject to the proposed CAFO requirements.
- Immature swine weighing less than 55 lbs – immature swine are counted only when confined at a stand alone nursery.
- Chickens – all broilers and layers, regardless of age, size, type of watering system, or manure handling system.
- Turkeys – all turkeys, regardless of age or size.
- Ducks – all ducks, regardless of age or size.
- Horses – all horses, regardless of age or size.
- Sheep and lambs – all sheep and lambs, regardless of age or size.

Definition of an AFO

Before a livestock or poultry operation can be considered a CAFO it must first meet the definition of an AFO. The language in the current regulation defines an AFO as a "lot or facility where animals have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12 month period; and where crops, vegetation, forage growth, or post-harvest residues are not sustained over any portion of the lot or facility in the normal growing season". Confusion over the interpretation of the amount of vegetation that is sustained has made this definition difficult to implement. The intent of the definition was to exclude pastures and rangeland that were largely covered with vegetation, but was intended to include feedlots and other confinement areas with incidental vegetative growth over only a small portion of the area.

Because of this ambiguity, EPA is proposing to revise the regulatory language that defines AFO as follows: "An animal feeding operation or AFO is a facility where animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12 month period. Animals are not considered to be stabled or confined when they are in areas such as pastures or rangeland that sustain crops or forage growth during the entire time that animals are present. Animal feeding operations include both the production area and land application area".

Some key points concerning the proposed definition of an AFO are as follows.

- If animals are in the facility for any portion of the day they are considered to be in the facility for a full day.
- Days start and end at midnight. Animals confined from 6:00 p.m. to 6:00 a.m. would be considered to be confined for two days.
- The 45 days do not have to be consecutive.
- The 12 month period does not have to correspond to the calendar year.
- Does not have to be the same animals in the lot or facility for the minimum 45 days.
- Winter feeding areas (dirt lots) with nominal vegetative growth while animals are present, even if substantial growth of vegetation occurs during months when animals are kept elsewhere, would be considered to meet the definition of an AFO.

- An AFO includes both the production area and the land application area. The term production area includes the animal confinement area, manure storage areas (lagoon, pile, shed, etc.), feed storage areas (bin, silo, silage bunker, etc.), and waste containment areas (berms, diversions, etc.). The term land application area would include any land to which a CAFOs' manure and wastewater is applied that is under the control of the CAFO owner or operator, whether through ownership or a lease or contract.

Definition of a CAFO

In the proposed regulation, EPA is co-proposing two alternative ways to determine which AFOs will be further defined as CAFOs and be required to apply for and operate in compliance with an NPDES permit. The first alternative proposal is a three-tier structure and the second alternative proposal is a two-tier structure. Under the three-tier structure, an operation would be classified as a CAFO if:

(1) The operation has more than 1,000 animal units (AU), or

(2) The operation has 300 to 1,000 AU and meets any of the following conditions: (a) there is direct contact of animals with waters of the U.S., (b) there is insufficient storage and containment at the production area, (c) there is evidence of a discharge from the production area within the last five years, (d) the production area is located within 100 feet of waters of the U.S., (e) the operator does not have, or is not implementing, a Permit Nutrient Plan [PNP], or (f) more than 12 tons of manure is transported off-site to a single recipient annually, unless the recipient has complied with the requirements for off-site shipment of manure, or

(3) The operation has less than 300 AU but is determined by EPA or the state NPDES regulatory authority to be a significant contributor of pollutants to waters of the U.S. No AFO with less than 300 AU may be designated as a CAFO unless pollutants are discharged (a) through a manmade ditch, flushing system, or other manmade device, or (b) directly into waters of the U.S. that originate outside of the facility and pass over, across, or through the facility or come into direct contact with the confined animals. A permit can only be required of operations with less than 300 AU after the permitting authority has conducted an on-site inspection.

Under the second co-proposed alternative, the two-tier structure, an operation would be classified as a CAFO if:

(1) The operation has 500 or more AU, or

(2) The operation has less than 500 AU but is determined by EPA or the state NPDES regulatory authority (on a case-by-case basis) to be a significant contributor of pollution to waters of the U.S. Factors that will be considered include (a) size of the operation, (b) amount of waste reaching waters of the U.S., (c) location of the operation, (d) means of conveyance of the waste, (e) slope, vegetation, rainfall, and other factors affecting the likelihood or frequency of discharge of animal wastes or process waters, and (f) other relevant factors.

EPA has estimated that 31,930 operations would be potentially classified as CAFOs under the proposed three-tier structure, and that 25,540 operations would be potentially classified as CAFOs under the proposed two-tier structure.

Other Issues Related to CAFO Definition

Several other proposed revisions to the existing CAFO regulations will impact how a CAFO is defined. Some of these include:

- EPA is proposing revisions to how animal operations with mixed types of animals are evaluated. In the existing regulation, animal operations are required to add together the number of AU from all animal types at the facility, using a mixed animal calculation (formula). If the cumulative number of mixed animal types exceeded 1,000 AU, the operation was defined as a CAFO. EPA is proposing to eliminate the mixed animal calculation and simply evaluate the number of each species at an operation separately to determine if an AFO is also a CAFO. For example, operations with mixed animal types that do not exceed the size threshold for any single livestock or poultry category would not be defined as a CAFO. However, if any one species exceeds the CAFO threshold, all confined animals (and their wastes) at the operation would be subject to the permit requirements.
- With the proposed revisions, two or more AFOs under common ownership are considered to be a single operation if they adjoin each other or use a common area or system for the disposal of waste (e.g., stored in the same pond or lagoon or land applied on commonly owned fields). The cumulative total of animals (of a given species) confined in the

adjoining facilities would be counted to determine if the operation is a CAFO.

- Due to confusion among the regulatory community concerning the definition of the term animal unit or AU, EPA has proposed to eliminate the use of the term in the revised regulation. Rather, they propose using the total number of head for purposes of defining an operation as a CAFO. EPA would simply use the term "CAFO" to refer to facilities that are either defined or designated as such. Table 1 describes the number of head for different animal types that are equivalent to the proposed AU thresholds for the three-tier and two-tier structures.
- The current CAFO definition provides that "no animal feeding operation is defined as a concentrated animal feeding operation ... if such animal feeding operation discharges only in the event of a 25-year, 24-hour storm event". EPA is proposing to eliminate the 25-year, 24-hour storm event exemption from the CAFO definition. Also, it is proposed to remove the 25-year, 24-hour storm event as a design specification for swine, poultry, and veal CAFOs.

NPDES Permit Requirements for CAFOs

All operations that are determined to be CAFOs (either by definition or by designation) are required to apply for and operate in compliance with an NPDES permit. However, if the owner or operator of the CAFO believes that the operation does not have the potential to discharge pollutants to the waters of the U.S. from either its production area or its land application areas, they can submit documentation supporting their claims of no discharge potential to the permitting authority in lieu of a full permit application. If the permitting authority agrees that the CAFO does not have the potential to discharge, the CAFO would not be required to apply for and obtain an NPDES permit. However, in the event the unpermitted CAFO does indeed have a discharge, it would be in violation of Clean Water Act provisions against discharging without a permit and would be subject to possible enforcement actions. Additionally, no operation that is defined or designated as CAFO can receive a no potential to discharge determination if they have had a discharge in the past five years.

Table 1. Animal equivalents for proposed animal unit (AU) thresholds.[a]

	Number of animals equal to:		
Animal type	**300 AU**	**500 AU**	**1,000 AU**
Beef cattle and heifers	300	500	1,000
Veal cattle	300	500	1,000
Mature dairy cattle	200	350	700
Swine weighing over 55 lb	750	1,250	2,500
Immature swine weighing less than 55 lb	3,000	5,000	10,000
Chickens	30,000	50,000	100,000
Turkey	16,500	27,500	55,000
Ducks	1,500	2,500	5,000
Horses	150	250	500
Sheep or lambs	3,000	5,000	10,000

[a]Under the three-tier structure, an operation would be classified as a CAFO if it (a) has more than 1,000 AU, (b) has 300 to 1,000 AU and meets certain conditions, or (c) has less than 300 AU and is determined by the permitting authority to be a significant contributor of pollutants to waters of the U.S. Under the two-tier structure, an operation would be classified as a CAFO if it (a) has 500 or more AU or (b) has less than 500 AU and is determined by the permitting authority to be a significant contributor of pollutants to waters of the U.S.

Types of NPDES CAFO Permits

NPDES permits are issued by EPA (the EPA Region is the permitting authority in the states of Alaska, Arizona, Idaho, Massachusetts, New Hampshire, and New Mexico) or by states that are authorized to administer the NPDES permits. There are two types of NPDES permits that can be issued by the permitting authorities, a general permit or an individual permit. Both types of NPDES permits would be issued for a five year period.

A general NPDES permit is developed by the permitting authority and can cover a number of facilities with similar characteristics within a defined geographical area (such as operations within political boundaries or within a watershed). In developing a general permit, the permitting authority develops the draft permit and associated fact sheet, issues a public notice, allows time for public review of the draft permit, addresses public comments concerning the draft permit, creates an administrative record, and issues the final permit. Once the final permit is issued, facilities that desire to be covered under the general permit submit a Notice of Intent (NOI) to the permitting authority that indicates their intent to seek coverage under the general permit. The following information should be contained in the NOI:

(a) Legal name and address of the owner or operator.
(b) Facility name and address
(c) Type of facility or discharges.
(d) Receiving stream or streams.
(e) Type and number of animals at the CAFO.
(f) Physical location, including latitude and longitude of the production area.
(g) Topographic map extending one mile beyond the facility's boundary that shows potential discharge points, surface water bodies in the area, ground water aquifers that may be hydrologically connected to surface waters, and depth to ground water.
(h) Acreage available for agricultural use of manure and wastewater.
(i) Estimated amount of manure and wastewater to be transferred off-site.
(j) Name and address of any other entity with substantial operational control of facility.
(k) Copy of the draft PNP [if a new facility] or the status of the development of the PNP [existing facility].
(l) If facility is to be located in an area that is determined to have vulnerable ground water, then a hydrologist's statement that the ground water under the production area of the facility is not hydrologically connected to surface water should be submitted.

Once the NOI has been properly submitted, the permitting authority may then grant the operation coverage under the general permit, request additional information before making a determination, or require the facility to apply for an individual NPDES permit.

Individual NPDES permits are specifically designed for and issued to a single operation. The proposed revisions to the CAFO regulations do not specify where individual permits, rather than general permits, must be used. However, the proposed regulation does require the permitting authority to conduct a public process for determining the criteria that would be used to specify if an operation should apply for an individual permit. In addition to any criteria developed from the public process, the proposed regulation would include the following CAFO-specific criteria as requirements for individual permits:

- CAFOs located in an environmentally or ecologically sensitive area.
- CAFOs with a history of operational or compliance problems.
- CAFOs that are exceptionally large operations as determined by the permitting authority.
- CAFOs that have undergone (or is planning to undergo) significant expansion.

Co-Permitting

EPA is proposing that entities that exercise "substantial operational control" over CAFOs be co-permitted on the NPDES permit along with the owner or operator of the facility. The term "substantial operational control" would include (but not be limited to) entities that (a) directs the activities of persons working at the CAFO either through contract or direct supervision of, or on-site participation in, activities at the facility, (b) owns the animals, or (c) specifies how the animals are grown, fed, or medicated. States could also develop additional factors to address their specific needs and circumstances. The term "owner or operator" means any person who owns, leases, operates, controls or supervises the facility.

The proposed regulation provides latitude for the permitting authority to make co-permittees jointly responsible for all of a CAFOs permit requirements, or to allocate individual responsibility for various aspects of an operation to any of the co-permittees. However, all permittees would be held jointly responsible for ensuring that any excess manure (i.e., manure exceeding what can be properly managed on-site) is handled in an environmentally appropriate manner.

EPA has also identified some alternatives to co-permitting in the proposed regulation that are under consideration. Under one alternative approach, EPA would waive the co-permitting requirement for states and processors that implement effective and enforceable programs for managing excess manure and nutrients. A second alternative would not require co-permitting if the processor develops an approved environmental management system (EMS) that is implemented by all of its contract producers and is regularly audited by an independent third party for compliance. Other alternatives to co-permitting that may have arisen during the public commenting period will also be evaluated.

Facility Closure

It is proposed that permitted CAFOs which cease operations should retain their NPDES permit until such time as the facilities are properly closed (i.e., no longer have the potential to discharge). Similarly, it is proposed that if a facility ceases to be an active CAFO (e.g., it decreases the number of animals below the threshold that defined it as a CAFO), the permit must be retained until all wastes that were generated while the facility was a CAFO no longer have the potential to reach waters of the U.S. Proper closure includes the removal of water from lagoons and stockpiles, and proper disposal of wastes, which may include land application of manure and wastewater in accordance with the conditions in the NPDES permit.

Technology Requirements for CAFOs

EPA is proposing several changes to the effluent limitations guidelines and standards (ELGs) for CAFOs. Included in the proposed changes are guidelines concerning animal confinement and manure storage areas, as well as land application and off-site transfer of manure. CAFOs that would be subject to the proposed ELGs include all beef, dairy, swine, chicken, and turkey subcategories as defined under either the three-tier or two-tier structure. Horse, sheep and lambs, and duck CAFOs would not be subject to the ELGs.

The effluent limitations section in the NPDES permit serves as the primary mechanism for controlling discharges of pollutants to receiving waters. EPA is proposing several technology-based effluent limits to ensure discharges of pollutants are controlled.

Permit Nutrient Plans (PNP)

EPA is proposing to require all CAFO operators to develop and implement a PNP. A PNP is a site-specific plan that describes how a CAFO owner or operator intends to meet the effluent discharge limitations and other requirements of the NPDES permit. The PNP must be developed within three months (90 days) of submitting an application for an individual NPDES permit or a NOI for coverage under a general NPDES permit, and must be developed or reviewed and modified by a certified planner. As changes occur to the CAFO, or as new technologies and production practices become available, the PNP would need to be modified and updated. The following is a brief description of what must be included in a PNP.

General Information: The general information section provides an overview of the PNP and would contain a Cover Sheet and an Executive Summary. The Cover Sheet would include the name and location of the operation, the name and title of the owner or operator, the name and title of the person who prepared the PNP, and the date (month, day, year) the PNP was developed and (if appropriate) amended. The Executive Summary would briefly describe the operation in terms of (a) herd or flock size, (b) total animal waste produced annually, (c) crop production for the 5 year permitting period, including a description of the expected crop rotation and realistic yield goal, (d) indications of field conditions for each field resulting from the phosphorus [P] method used [e.g., Phosphorus Index, Phosphorus Threshold, Soil Test Phosphorus] to determine manure application rates, (e) manure and wastewater application rates, (f) total number of acres that will receive manure, (g) nutrient content of manure, (h) amount of manure that will be transferred off-site, (i) manure collection, handling, storage, and treatment practices, and (j) identification of the watershed or watersheds in which fields receiving manure are located or the nearest surface water body.

Animal Manure Production: This subsection details the types and quantities of animal manures that will be generated by the CAFO, as well as the manure sampling techniques and results of the manure analysis. Also included would be the maximum livestock capacity of the CAFO and the annual livestock production.

Animal Manure Handling, Collection, Storage, and Treatment: This subsection provides details of the best management practices (BMPs) that will be used to protect surface and groundwater from contamination during the handling, collection, storage, and treatment of animal wastes. It would also contain information pertaining to evaluations of potential water contamination sources from existing animal waste handling, collection, storage, and treatment practices, and calculations used to determine needed storage capacity.

Manure Land Application Sites: This subsection provides details of field identification (including county and watershed code where application fields are located), total acres for the operation under the control of the CAFO (owned, rented, leased, etc.), total acres where manure and wastewater will be applied, soil sampling techniques, soil testing results, and the P rating for each field based on the selected assessment tool.

Land Application of Manure: This portion of the PNP provides details of crop production for the CAFO and animal manure and wastewater applications to the crop production areas. Included would be identification of all planned crops, expected crop yields and the basis for the yield estimates, crop planting and harvesting dates, crop residue management practices, and nutrient requirements of the crops to be grown. This section would also include the calculations used to develop the application rate, including nitrogen (N) credits from legume crops, available nutrients from previous manure applications, nutrient credits from other fertilizer sources, and nutrient losses (particularly N) that might occur due to method of application. Methods for determining manure application rates are discussed in more detail in a separate section of this paper. The dates of animal manure applications, calibration of application equipment, and rainfall amounts 24 hours before and after application would be included as well.

Other Uses/Off-Site Transfer of Manure: The final subsection of the PNP details any alternative uses or off-site transfer of animal manure and wastewater that the CAFO will use. If alternative uses are employed, a complete description of the alternative uses would need to be included. For off-site transfer of manure, the name and location of the recipient, the quantity transferred, and the date transferred would need to be included. Additional information on the off-site transfer of manure is included in a separate section of this paper.

In practical terms, the proposed PNP is the subset of activities in a Comprehensive Nutrient Management Plan (CMNP) that are directly connected with the effluent guidelines and NPDES permit requirements. In fact, EPA expects that many CAFOs will satisfy the requirement to develop a PNP by developing a CNMP. However, the PNP goes beyond the broad requirements of a CMNP and contains specific management practices and monitoring guidelines that must be implemented by a CAFO. For example, the proposed regulations specify the following components and limitations that must be included in the PNP:

- Daily inspections of automated watering systems for animals to ensure they are not leaking or spilling.
- Sample each different animal manure source at least once annually (up to twice annually if manure is applied more than once or removed to be sent off-site more than once per year) and have analyzed by an accredited laboratory for N, P, potassium (K), and pH.
- Weekly inspections of storm water diversions at the animal confinement and manure storage areas to ensure they are free from debris.
- Weekly visual inspections of manure storage and treatment facilities to ensure structural integrity (e.g., for liquid impoundments, the berms would be checked for leakage, seepage, erosion, vegetation, animal access, freeboard, or other signs of structural weakness). Deficiencies would need to be identified and corrected within a reasonable time frame.
- Permanently install depth markers in liquid impoundments (lagoons, ponds, tanks, etc.) that are open and capture precipitation and those that are closed or covered, and record depth during weekly inspections. The marker should clearly delineate the maximum volume that should be maintained to allow containment of the 25-year 24-hour storm event. As an alternative to depth markers, remote sensors which monitor liquid levels in impoundments can be used.
- Zero discharge from a facility designed, maintained, and operated to hold the waste and wastewater, including storm water from runoff plus the 25-year 24-hour storm event.
- Handle mortalities in ways that prevent contribut-

ing pollutants to waters of the U.S. (e.g., transferring mortalities to rendering facilities, burial in properly sited lined pits, and composting).

- Develop an emergency response plan for animal waste spills and releases.
- Detailed farm map or aerial photo that identifies location and boundaries of the operation, individual field boundaries, field identification and acreage, soil types and slopes, location of nearby surface waters and other environmentally-sensitive areas (e.g., wetlands, sinkholes, agricultural drainage wells, above ground tile drain intakes, etc.), and areas where application is restricted.
- Sample soils and have analyzed by an accredited laboratory for P at least once every three years.
- Animal manure and wastewater applications cannot exceed the crops requirement for N. However, as discussed later, application rates may be limited to agronomic requirements for P, or completely restricted.
- Animal wastes cannot be applied to wetlands or within 100 feet of a sinkhole or water source (river, stream, lake, pond, or agriculture drainage system).
- Comply with specific requirements that will be developed by the permitting authority pertaining to the application of manure and wastewater to the land (including how to calculate the allowable manure application rate, specify timing restrictions on when it is appropriate to apply manure to frozen, snow covered, or saturated land, how to control impacting groundwater in sensitive areas [i.e., karst areas, etc], and closure of facilities).
- Test and calibrate all manure application equipment annually to ensure that manure is land applied in accordance with the proper application rates established in the NPDES permit.
- Review the PNP annually and amend if practices change at either the production area or at the land application area, and submit notification of changes to the permitting authority. Examples of changes in practice that would necessitate an amendment to a PNP include a substantial increase in animal numbers (more than 20%), a change in the cropping program which would significantly alter land application of manure and wastewater, elimination or addition of fields receiving applications, and changes in manure collection, storage facilities, treatment, or land application method.

To document that CAFO owners or operators are complying with the monitoring requirements of the PNP and the NPDES permit, EPA is proposing that the following records be maintained at facility and be available upon request to the permitting authority:

- A copy of the entire PNP and supporting data, including the name of the specialist that prepared or approved the PNP.
- Records documenting all visual inspections, findings, and preventative maintenance.
- Records documenting manure applications and crop production, including records of manure and soil sampling and analysis.
- Records of total volume or amount of manure and wastewater generated.
- Records of rainfall, including the duration, amount, and estimated overflow (if any).
- Emergency response plan.
- Records of mortality management.
- Records of manure transfers to off-site recipients (may also include off-site recipient certification of proper application).

Public Availability of the PNP

EPA is proposing to require the owner or operator of a permitted CAFO to make a copy of the entire PNP, or at least a portion of the PNP (along with the permit application) available to the public for review during the public notice and comment process. At a minimum, CAFOs will be required to make a copy of the PNP Cover Sheet and Executive Summary available to the public. However, there is disagreement on whether the entire the PNP should be available to the public. Some stakeholders have claimed that portions of the PNP contain confidential business information, and should be entitled to protection and not made available to the public. EPA requested comments on this issue during the commenting period, and will utilize this information in drafting the final regulation.

EPA does not propose a specific means for making the PNP available to the public. However, this could be accomplished through (1) maintaining a copy of the PNP at the facility and making them available to the permitting authority as publicly viewable documents upon request, (2) maintaining a copy of the PNP at the facility and making them available directly to the requestor, (3) placing a copy of the PNP at a publicly accessible site, such as the library, or (4) submitting a copy of the PNP to the permitting authority where they can be viewed by the public on request.

Determining Manure Application Rates

In determining the allowable manure application rate for a CAFO, EPA is proposing to adopt the three methods contained in the USDA Natural Resources

Conservation Service's (NRCS) nutrient management standard (Standard 590). These three methods are the (1) Phosphorus Index, (2) Phosphorus Threshold Level, and (3) Soil Test Phosphorus Level. Individual states (Departments of Agriculture and [or] State NRCS agencies) are developing state nutrient standards which incorporate one of these methods, and EPA is proposing to require that each permitting authority adopt one or more of these methods as part of the State NPDES program. The permit would require the permittee to develop the appropriate land application rates in the site specific PNP based upon the state's adopted method.

Phosphorus Index: The Phosphorus Index is a means to objectively assess the risk that P will be transported off the application field to surface waters. Many states are developing a Phosphorus Index for their state in response to the NRCS 590 Standard. The Phosphorus Index establishes a relative value of low, medium, high, or very high risk of P transport in a field (alternatively, the index may establish a numeric ranking of risk).

At a minimum, the Phosphorus Index must address the following factors: (a) soil erosion, (b) irrigation erosion, (c) runoff class, (d) soil P test, (e) P fertilizer application rate, (f) P fertilizer application method, (g) organic P source application rate, and (h) organic P source application method. Other factors that might also be included in the Phosphorus Index are subsurface drainage, leaching potential, distance from edge of the field to surface water, and priority of receiving water.

Each factor comprising the Phosphorus Index is listed in a matrix with a score assigned to each factor. Each factor is also assigned a weight depending on its relative importance in the transport of P. The weighted score for each factor in the Phosphorus Index is summed to yield an overall score. If the overall score for the index is low or medium, then manure may be applied to meet the N requirements of the crop(s). If the overall score for the index is high, manure could only be applied at a rate to meet the crop removal rate for P. If the overall score for the index is very high, application of manure would be prohibited. As an example, the Phosphorus Index developed for Kentucky is shown in Table 2.

Phosphorus Threshold: The Phosphorus Threshold is a measure of P in the soil that reflects the level of P at which its movement in the field is acceptable. Because of differences among soils in their ability to bind and hold P, states that choose to adopt this method in their state nutrient management standard will need to establish a Phosphorus Threshold for all types of soils found in their state. At present, many scientists are using a soluble P concentration of 1 ppm as a measure of acceptable P movement.

When using the Phosphorus Threshold, manure may be applied to meet the crop's N requirement if the concentration of P in the soil is less than three-quarters (¾) of the threshold. When soils have a P concentration between ¾ and twice the Phosphorus Threshold, manure may only be applied to meet the crop's removal rate for P. For soils which have a P concentration greater than twice the Phosphorus Threshold, no manure may be applied.

In Kentucky, a Phosphorus Threshold of 533 lb of soil test P per acre has been adopted. Table 3 shows the ranges of Phosphorus Threshold values that will be used to determine manure application rates in Kentucky.

Soil Test Phosphorus: Soil Test Phosphorus is an agronomic soil test that measures for P. This method is intended to identify the point at which the P concentration in the soil is high enough to ensure optimum crop production. Once that concentration is reached (generally reported as a "high" value from soil testing laboratories) P is applied at the crop removal rate. If the Soil Test Phosphorus value reaches a "very high" concentration, then no manure may be applied.

Much like the Phosphorus Index, the Soil Test Method establishes requirements based on low, medium, high, and very high soil conditions, and applies the same P application restrictions as the index. States that adopt the Soil Test Phosphorus method will need to establish the soil concentration ranges for each soil type and crop in their state.

Off-Site Transfer of CAFO Manure

It is possible that some CAFOs will generate more manure than its crops can utilize, necessitating the need for off-site transfer of manure. To ensure the proper handling of manure that is moved off of the CAFO, EPA is co-proposing two options for off-site recipients and CAFO owners or operators.

Option 1: Under this option, owners or operators of CAFOs would be required to obtain certification from off-site land appliers that they are applying the manure at proper agricultural rates. As defined in the proposed regulation, proper agricultural rates means that the recipient shall determine the nutrient need

Table 2. Kentucky Phosphorus Index (PI).[a]

Field feature	Weighting factor	Field feature value ratings: Low (1 point)	Medium (2 points)	High (4 points)	Very high (8 points)
1. Hydrologic soil group	1	A	B	C	D
2. Residual soil test P level	3	Between 400-500	Between 501-800	Between 801-1066	Above 1066[b]
3. Field slope percent	1	< 2	2-5	6-12	> 12
4. Land cover percent (after application)	3	60-90	30-60	15-30	0-15
5. Vegetative buffer width (ft)	3	> 29	20-29	10-19	< 10 or no buffer
6. Application area is in a watershed identified as being impaired due to agricultural applied nutrients	1	No			Yes
7. Application timing	3	Jun-Sept	Apr, May, Oct, Mar, or Nov w/ winter cover	Mar or Nov w/o winter cover, Feb w/ winter cover	Dec, Jan, Feb
8. Application method	3	Injected	Surface applied and incorporated within 48 h	Surface applied and incorporated within 1 mo	Surface applied and not incorporated for greater than 1 mo
9. Downstream distance from application area to spring, stream or waterbody (ft)	2	Over 150	50-150	0-50	Adjacent
10. MLRA (county location)	1	Bluegrass	All others		

[a]Multiply the weighting factor by the appropriate value rating to determine total points for a specific field feature.
[b]Additional P will not be applied to fields when the soil test P is above 1066.

Field vulnerability for P loss: Total points from PI	Generalized interpretation of PI	Basis for manure applications
< 30	LOW potential for P movement from the field. Low probability of an adverse impact to waterbodies.	Crop needs for N
30-60	MEDIUM potential for P movement from the field. The chance of organic matter and nutrients getting into waterbodies exist. Buffers, setbacks, lower manure rates, cover crops, and crop residues practices alone or in combination may reduce impact.	Crop needs for N
61-112	HIGH potential for P movement from the field. The chance of organic matter and nutrients getting to waterbodies is likely. Buffers, setbacks, lower manure rates, cover crops, crop residues, etc. in combination may reduce impact.	Crop removal for P
> 112	VERY HIGH potential for P movement from the field and an adverse impact on waterbodies.	No manure applications

SOURCE: Adapted from Kentucky NRCS Conservation Practice Standard, Nutrient Management, Code 590.

Table 3. Phosphorus Threshold (PT) values for Kentucky.[a,b]

PT values	Nutrient for determining manure application rate
Below _ PT (below 400 lb soil test P)	Application rate based on N requirement of crop
Above _ and below 1-_ times the PT (400-800 lb soil test P)	Application rate based on crop removal rate for P
Above 1-_ and below 2 times the PT (801-1066 lb soil test P)	Application rate based on _ the crop removal rate for P
Above 2 times the PT (above 1066 lb soil test P)	No manure application allowed

[a]The PT in Kentucky is 533 lb of soil test P per acre.
[b]Adapted from Kentucky NRCS Conservation Practice Standard, Nutrient Management, Code 590.

of its crops based on realistic yields, sample its soil at least once every three years to determine existing nutrient content, and not apply manure in quantities that exceed the land application rates calculated using the state's standard for either the Phosphorus Index, the Phosphorus Threshold Level, or the Soil Test Phosphorus Level. The CAFO owner or operator would also be required to maintain records of manure transfers (including the name of the recipient and the amount transferred), and provide the recipient with the results of the manure analysis and a brochure (provided by the permitting authority) that describes the recipient's responsibilities for proper management of the manure to prevent discharges of pollutants to waters of the U.S. EPA is proposing to exempt the certification requirement for off-site recipients who receive no more than 12 tons of manure per year (approximately the amount that could be appropriately applied to 5 acres of land). In addition, EPA is proposing to waive the off-site certification provision in states that are implementing an effective, enforceable program that addresses excess manure generated by CAFOs.

If CAFO-generated manure is transferred to manure haulers who will not themselves land apply the manure, EPA is proposing that the CAFO owner or operator must: (1) obtain the name and address of the individual or entity that will receive the manure; (2) provide the manure hauler with an analysis of the nutrient content of the manure, that is to be given to the recipient of the manure; and (3) provide the manure hauler with a brochure to be given to the recipient describing the recipient's responsibility to properly manage the land application of manure.

Option 2: Under this option, CAFO owners or operators would not be required to obtain the certification described above from off-site manure recipients, but would be required to maintain records of transfer and provide the aforementioned information to off-site recipients.

Direct Hydrological Link

CAFOs would need to perform an assessment to determine if the operation has a direct hydrological connection to surface water. A hydrological connection refers to the interflow and exchange between surface impoundments and surface water through an underground corridor or groundwater.

CAFOs with a direct hydrological link would be required to install monitoring wells (located up gradient and down gradient of the production area), and sample groundwater from the wells at a minimum of twice per year to ensure pollutants are not being discharged through groundwater to surface water. The samples would be monitored for nitrate, ammonia, total coliform, fecal coliform, total dissolved solids (TDS), and total chloride.

Water Quality-Based Requirements

In cases where technology-based effluent limitations are insufficient to meet water quality standards, the permit writer must develop more stringent water quality-based effluent limits. This could include such things as (a) synthetic liners for lagoons to address a direct hydrological connection to surface waters, (b) covers for lagoons to prevent rainwater from causing overflows, (c) allowing discharges only from catastrophic storms and not from chronic storms, (d) pollutant limits in the overflow, (e) specified treatments such as grassed waterways for the overflows discharges, and (f) others.

Final Regulations and Implementation

EPA is required under a consent decree to take final action on the proposed rule by December 15, 2002. It is anticipated that the final regulation will be published in the Federal Register in January 2003. It will take some time for states to revise their existing programs, receive approval on the revised program from EPA, and develop new or revised CAFO general permits. Thus, EPA expects that these changes will not be in effect until approximately January, 2006.

Because of the time lag between publication of the final regulation and when states will be ready to issue CAFO general permits, EPA has also proposed to delay the effective date for when the regulatory revisions would be required for newly defined CAFOs. Operations that are brought within the regulatory definition of a CAFO for the first time under the final regulation would not be defined as CAFOs (and be required to obtain an NPDES permit) until January, 2006. It should be noted that EPA is proposing this delayed effective date only for the proposed regulatory changes that affect which operations would be defined as CAFOs. All other provisions of the revised rules would become effective 60 days after the final rule is published. Therefore, any operations that meet the existing definition of a CAFO and are being permitted 60 days after publication of the final rule would be subject to the final regulations at that time. CAFOs that currently have an NPDES permit would not be subject to the new permit requirements until their permit is re-issued after its 5-year term expires.

Implications

Changes in the livestock and poultry industries and environmental concerns related to the production of livestock and poultry have prompted EPA to propose revisions to existing regulations for CAFOs. Under the proposed revisions, more livestock and poultry operations will be classified as CAFOs. CAFOs will be required to obtain an NPDES permit and meet its more stringent conditions. These regulations will require CAFO owners or operators to develop site-specific PNPs for their operations, and will substantially increase the monitoring, reporting, and record-keeping requirements for CAFOs.

References Cited

EPA. 2001. National Pollutant Discharge Elimination System (NPDES) Permit Regulation and Effluent Limitations Guidelines (ELS) and Standards for Concentrated Animal Feeding Operations. Available: http://cfpub.epa.gov/npdes/regresult.cfm?program_id=7&view=all&type=3

EPA. 2001. State Compendium: Programs and Regulatory Activities Related to Animal Feeding Operations. Available: http://cfpub.epa.gov/npdes/afo/statecompend.cfm?program_id=7

NRCS, 2001. Kentucky Natural Resources Conservation Service Conservation Practice Standard, Nutrient Management, Code 590. Available: http://www.ky.nrcs.usda.gov

Modifying Diets To Reduce Odors

Alan L. Sutton , Professor, Animal Sciences
Purdue University. West Lafayette, IN 47907

Summary

Modifying the pig's diet to reduce odors is feasible and practical. Examples are presented on manipulating the pig's diet to alter nutrient excretion, emissions of ammonia, hydrogen sulfide, selected volatile organic compounds and other odorants, and olfactometry responses. Reducing the crude protein level and supplementing with synthetic amino acids; addition of low levels (<10%) of fermentable nonstarch polysaccharides; and the addition of pH and buffering feed ingredients have promise of reducing odors and gaseous emissions. Manipulation of the microflora in the pig's digestive tract shows indication of some influence on odors, however, research in this area has not received as much attention. Techniques to increase the availability and retention of nutrients can reduce excretions of compounds commonly causing odors. Economics is still a major issue determining if certain manipulation technologies will be adopted. Research to fine-tune these altered diets for commercial production systems is needed for encouraging implementation.

Introduction

Manure is primarily a mixture of urine and feces excreted from pigs that contains undigested dietary components, endogenous end products, excreted excess absorbed nutrients, and indigenous bacteria from the lower gastrointestinal tract (GIT) of the pig. Manure contains a variety of organic compounds, complex to simple in nature, inorganic compounds, and potentially feed additives depending upon the makeup of the diet. Pig feces and urine both contain considerable amounts nutrients that can be used effectively as a fertilizer substitute or other alternative by products. However, anaerobic microbial degradation of manure often creates gaseous emissions and odors.

Numerous compounds (ranging from 160 to more than 400) have been identified from the anaerobic degradation of livestock manures. They have been generally grouped as volatile amines, sulfides, disulfides, organic acids, phenols, alcohols, carbonyls, nitrogen heterocycles, esters, fixed gases and mercaptans. Hobbs, et al., (1995) identified fifteen specific volatile organic compounds (VOC) as primary odor causing compounds from manures with available odor thresholds shown in Table 1. The sensitivity of individual compounds by olfactometry threshold detection varies widely. In general, sulfur-containing compounds are among the group of lowest detection thresholds from manure. A major challenge for identifying specific odorous compounds from manures is that analytically derived gas concentrations and olfactometry measurements are not highly related (Gralapp, et. al, 2001; Van Kempen, et al., 2002). Methods that have been tested are GC-MS, electronic nose, scentometers, diffusion tubes, Fourier transform infrared spectrometry (FTIR) and olfactometry with the FTIR showing the most promise. Moreover, there are confounding effects of mixtures of different compounds on olfactometry detection. Some VOC can change chemical form, thus, precise analytical detection and quantification of air samples is also a challenge.

Volatile organic compounds, short-chain volatile fatty acids (VFA) and other volatile carbon-, nitrogen-, and sulfur-containing compounds in feces from microbial fermentation in the GIT of the pig can be emitted immediately after excretion. Furthermore, the release of ammonia (NH_3) in the urine from the enzymatic conversion of urea can also occur within a short time after excretion. Several methods have been used to control odor emissions from manure in pork production. More recently, the effects of diet composition on excretion products related to odorous compounds have been studied. One approach is to provide the pig, as closely as possible, with essential available nutrients based upon its genetic potential for lean tissue deposition and stage of growth, so that nutrient excretion is minimal and a lower potential for creating compounds responsible for odor production. Enhancing the efficiency of nutrient utilization

Table 1. Odour detection thresholds for odorants present in pig slurry[a]

Compound	Odour detection threshold ($mg\ m^{-3}$)
Acetic acid	25-10,000
Propanoic acid	3-890
Butanoic	4-3000
3-Methyl butanoic acid	5
Pentanoic acid	.8-70
Phenol	22-4000
4-Methyl phenol	.22-35
Indole	.6
3-Methyl indole	.4-.8
Methanethiol	.5
Dimethyl sulfide	2-30
Dimethyl disulfide	3-14
Dimethyl trisulfide	7.3
Hydrogen sulfide	.1-180

[a] Hobbs, et al., (1997)

is another component which should reduce potential compounds that are responsible for creating odors. Another concept is to manipulate the bacteria in the GIT of the pig by inhibiting certain microbial groups or altering the fermentation of existing bacteria, thus, controlling odorous end products. Finally, changing diet composition may change the physical characteristics of urine and feces that control odor production. This paper presents an overview on how modification of the pig's diet can effect gaseous emissions and odors.

Nutrient Reduction

Improving Feed Efficiency. Any management procedure that improves the overall efficiency of feed utilization in a swine herd will generally reduce the total amount of manure produced, should reduce nutrient excretion and potentially the precursors of odor producing compounds. Using growth promoters such as antibiotics, β-agonists, and maintaining a high health status are examples of how one can improve feed conversion efficiency and reduce nutrient excretion. Use of therapeutic levels of feed grade antibiotics can improve feed efficiency from 5 to 15% and have reduced some isolated odor compounds (p-cresol; skatole). Copper sulfate addition to the diet has been shown to improve feed efficiency of 5 to 10% and has been shown to potentially reduce odors (Armstrong, et al., 2000).

Two experiments were conducted with crossbred barrows (Initial BW=84 kg) comparing the effects of corn-soybean meal, low crude protein diets with and without a β-agonist, ractopamine (RAC), on N and P retention and excretion, and odor emissions (Sutton, et al, 2001). The four dietary treatments (TRT) tested were: 1) 13.8% CP, 0.80% Lys control; 2) 16.1% CP, 1.10% Lys; 3) 16.1% CP, 1.10% Lys + 20 ppm RAC; and 4) 13.8% CP, 1.10% Lys+ 20 ppm RAC. Averaged across both experiments (Tables 2 and 3), the 16.1% CP diet with RAC decreased total N excretion by 10.7% or 2.49 g/d ($P<.05$) and total manure output by 3.9% or 149 g/day. The low crude protein diet (13.8%) with RAC further decreased N excretion by 34.2% or 7.65 g/d ($P<.05$). Slurry ammonium N (Table 4) was reduced 8-21% and 21-47% ($P<.05$) from pigs fed RAC at 16.1% and 13.8% dietary CP, respectively, compared to similar CP diets without RAC. Total VFA production (Table 5) was higher ($P<.05$) for the 16.1% CP diet with no RAC compared to the diets with RAC and was 21%, 28% and 23% higher ($P<.05$) at d 17, 35 and 64 of the trial, respectively, than the 13.8% CP diet + RAC. Olfactometry results (Table 6) indicated a detection threshold 51% higher ($P<.05$) for the 16.1% CP diet

Table 2. Nitrogen Excretion (Trial 1)*.

Dietary CP	13.8% CP		16.1% CP		
Ractopamine, 20 ppm	-	+	-	+	CV
Water Intake, mL	4800	4800	4800	4800	--
Feed Intake, g/d	2200	2200	2200	2200	--
Feces, g/d, as is	485[a]	654[b]	578[c]	609[c]	6.2
Urine, mL/d, as is	3040[a]	2622[b]	3038[a]	2690[b]	6.3
Manure, g/d as is	3525[ab]	3276[b]	3616[a]	3299[b]	5.4
N, % digested	88.4	88.5	88.7	88.9	1.8
P, % digested	58.9	56.7	51.3	53.7	10.4
N					
Intake, g/d +	49.8	52.6	59.1	59.1	0
Feces, g/d	5.8	6.0	6.6	6.5	13.9
Urine, g/d	18.8[a]	9.8[b]	23.5[c]	14.4[d]	14.8
Total N excreted, g/d	24.6[a]	15.8[b]	30.1[c]	21.0[d]	9.4
Retained, g/d	25.2[a]	36.7[b]	28.9[c]	38.1[b]	6.7

* No Covariates used
\+ Intakes calculated from analyzed dietary N and P values.
a,b,c,d Means with different superscripts differ by P< .05.

Table 3. Nitrogen Excretion (Trial 2)*

Dietary CP	13.8% CP		16.1% CP		
Ractopamine, 20 ppm	-	+	-	+	CV
Water Intake, mL	5600	5600	5600	5600	--
Feed Intake, g/d	2100	2100	2100	2100	--
Feces, g/d, as is	473.5	434.4	465.6	458.9	11.9
Urine, mL/d, as is	3650.3	3661.7	3722.7	3592.9	5.6
Manure, g/d as is	4124	4096	4188	4052	5.1
N, % digested	88.8	90.8	90.9	90.5	1.4
P, % digested	55.4	57.5	55.6	58.2	9.5
N					
Intake, g/d +	47.56	50.19	56.39	56.38	--
Feces, g/d	5.49	4.59	5.17	5.24	12.1
Urine, g/d	14.6[b]	9.03[c]	18.0[a]	13.7[b]	9.8
Total N excreted, g/d	20.1[b]	13.6[c]	23.2[a]	18.9[b]	6.2
Retained, g/d	29.1[c]	36.1[a]	33.9[b]	36.2[a]	3.5

* No Covariates used
\+ Intakes calculated from analyzed dietary N and P values.
a,b,c, Means with different superscripts differ by P< .05.

Table 4. Total Slurry Ammonium Nitrogen (Trial 1)

		Ammonium N, ppm			
Dietary CP	Ractopamine, 20 ppm	d 0[1]	d 17	d 35	d 64
13.8%	-	5063[a]	4612[b]	4279[a]	3745[a]
16.1%	-	6144[b]	5976[a]	5091[b]	4933[b]
16.1%	+	4170[c]	4218[b]	3390[c]	3453[ac]
13.8%	+	2706[d]	3004[c]	2691[d]	2954[c]
CV		11.98	7.06	10.67	11.07

[abcd] Differing superscripts within a column indicate significance at P<.05.
[1] Day of slurry incubation trial.

Table 5. Slurry Total Volatile Fatty Acid Content (Trial 1)

		Volatile Fatty Acids, mmol/L			
Dietary CP	Ractopamine, 20 ppm	D 0[1]	d 17	d 35	d 64
13.8%	-	53.32	105.52 [abc]	89.3 [ab]	82.26[ab]
16.1%	-	54.74	118.13 [a]	101.8 [a]	91.33[a]
16.1%	+	61.97	101.13 [bc]	79.1 [bc]	72.05[b]
13.8%	+	46.35	93.02 [c]	73.6 [c]	70.27 [b]
CV		8.26	12.44	12.30	16.08

[abc] Differing superscripts within a column indicate significance at P<.05.
[1] Day of slurry incubation trial

Table 6. Odor Detection (DT) and Recognition (RT) Levels (Trial 1)

		d 0[1]		d 17		d 35		d 64	
Dietary CP	RAC, 20 ppm	DT	RT	DT	RT	DT	RT	DT	RT
13.8%	-	3697[a]	2041[a]	1874[a]	1060[a]	1869[a]	1156[a]	1005[a]	573[a]
16.1%	-	3753[a]	2036[a]	1115[b]	567[b]	2942[c]	1688[b]	2053[b]	1204[b]
16.1%	+	3574[a]	1975[a]	2052[a]	1224[a]	2727[ac]	1587[cb]	1076[a]	587[a]
13.8%	+	3213[a]	1675[a]	1923[a]	1139[a]	4235[b]	2480[c]	1055[a]	587[a]
CV		58.31	61.97	75.52	82.34	71.69	66.82	65.66	78.38

[abc] Differing superscripts within a column indicate significance at P<.05.
DT=Detection Threshold, measure of when panelist correctly identified which air stream has a different odor from the other two air streams.
RT=Recognition Threshold, measure of when panelist can describe the odor.
[1] Day of slurry incubation trial

without RAC compared to the 13.8% CP diet without RAC at d 64. This indicated that a 13.8% CP diet + 20 ppm RAC could significantly decrease slurry ammonium N and VFA production in stored manure to help reduce odor emission.

Other feed management practices that enhances feed efficiency and reduces nutrient excretion are: fine grinding, pelleting and other feed processing techniques, reduced feed wastage, dividing the growth period into more phases (phase feeding) with less spread in weight between groups allows producers to more closely meet the pig's protein and other nutrient requirements, and split-sex feeding to meet the specific requirements of gender. However, the effects of these management technologies on odors have not been investigated.

Excessive Nutrient Levels. Often, a safety margin for diet ingredients is allowed so that variability of nutrients in feed ingredients and variation in pig biological responses can be reduced. Formulating the diets to meet the protein/amino acid requirements of pigs (National Research Council; NRC, 1998) without excessive levels above the requirements, however, is critical. Feeding excessive protein levels is not only wasteful and expensive, but it results in excessive N excretion and increased ammonia emission (Sutton, et al., 1999). Growing-finishing gilts (54 kg) were fed different dietary N levels to determine odors and nutrients from fresh manure and manure stored in anaerobic systems (Sutton, et al. 1998a). Corn-soy diets compared were (1) 10% CP (deficient protein diet); (2) 10% CP with four synthetic amino acids (lysine, methionine, threonine, tryptophan) supplemented to meet the pigs nutrient requirements (supplemented protein diet); (3) 13% CP (standard commercial diet); or (4) 18% CP (excess protein diet).

The amino acid supplemented protein diet reduced pH, ammonia N and total N in fresh manure compared to the other dietary treatments. Ammonia N levels were reduced 25%, 28%, and 40% in fresh manure on a dry matter basis and total N was reduced 20%, 28% and 42% in fresh manure on a dry matter basis when comparing the amino acid supplemented diet with deficient protein, standard and excess protein diets, respectively. Similar responses to the dietary treatments were evident during the anaerobic storage of the manure (Table 7). The pH of manure from pigs fed the amino acid supplemented protein diet was lower than the other dietary treatments. This was due to the reduction in excretion of urea in urine, since the lowered pH effect was in the urine. Ammonia N concentrations on a wet basis were reduced by 32%, 43% and 56% and total N levels in the manure

Table 7. Effect of diet on pH, and nitrogen components in fresh and stored manure[1].

Diet (%CP)	pH	DM	NH_4-N	TKN[2]
		%	%DM	%DM
Fresh manure				
Deficient (10)	7.80[a]	17.3[ab]	3.47[b]	7.40[b]
Suppl. (10 + AA)	7.33[b]	18.4[a]	2.61[c]	5.90[c]
Standard (13)	7.84[a]	16.0[b]	3.61[b]	8.16[b]
Excess (18)	8.13[a]	12.9[c]	4.35[a]	10.13[a]
SEM	.1	.6	.2	.4
		%	mg/L	mg/L
Stored manure				
Deficient (10)	7.58[a]	5.40[b]	4375[c]	5631
Suppl. (10 + AA)	6.94[b]	6.47[a]	2986[d]	4026[d]
Standard (13)	7.80[a]	5.64[b]	5239[b]	7012[b]
Excess (18)	7.97[a]	5.75[b]	6789[a]	8912[a]
SEM	.2	.3	309	331

[1]Different letter superscripts within a column are significant ($P<0.05$).
[2]TKN = Total Kjeldahl nitrogen

were reduced by 29%, 43% and 55% from pigs fed the amino acid supplemented protein diet compared to the deficient, standard and excess protein diets, respectively, in anaerobically stored manure. As expected, increased N excretion from excess protein in the diet led to increased ammonia emissions.

Total VFA concentrations were highest with the standard diet (13% CP) with a very high proportion of acetic acid. Conversely, VFA were reduced with the deficient and excess protein diets. There was likely an imbalance in C:N ratio or insufficient carbohydrate in the excess protein diet to promote enhanced microbial decomposition. Although the reduced pH in the amino acid supplemented diet was mostly due to increased VFA, the lower pH and less ammonia and total N excretion suppressed ammonia volatilization and other odorous compounds from stored manure. Prevalent concentrations of ethanol, propanol, dimethyl sulfide, dimethyl disulfide, and carbon disulfide were observed in gas collected from the anaerobically stored manure.

Nitrogen Manipulation

Fecal N arises from undigested dietary protein, intestinal secretions (mucin, enzymes, etc.), sloughed intestinal cells, and intestinal bacteria. Urinary N, largely in the form of urea, arises from the breakdown of absorbed dietary amino acids that are in excess of the amounts needed for lean tissue protein synthesis, and from the normal breakdown/turnover of body tissue proteins.

The use of high quality protein sources that have a good balance of amino acids (a high biological value) will allow one to meet the dietary requirement of the most limiting amino acid (usually lysine) at lower dietary protein levels than when low quality protein sources are used. The excesses of the other amino acids in the high protein diet are used for energy and the N is excreted as urea in the urine. Many nutritionists are formulating swine feeds on an "ideal protein" basis which the amino acids more closely match those needed for lean tissue protein synthesis and maintenance. Although the nutritionist cannot prepare a perfect amino acid balance from natural feed ingredients, the use of computers and having an array of different feed ingredients and synthetic amino acids allows nutritionists to produce diets that have reduced amino acid excesses while still meeting the pigs' amino acid requirements and productivity.

Several studies in Europe and the US have shown that with a 1% reduction in the crude protein of a pig diet and supplementation with the limiting synthetic amino acids will reduce ammonia emission into the air by 8 to 12% (Kendall, et al., 1998; Sutton, et al., 1999). Practical feeding studies with CP levels reduced from 19% to 13% resulted in a 47% to 59% reduced NH_3 emissions from building air. This reduction in dietary N also reduced manure odors by 40 to 86% and decreased p-cresol by 43% (Hobbs et al., 1996). Turner, et al., (1996), showed reduced ammonia emissions from manure in a pilot study of 79% by reducing the dietary CP level in the feed from 16% to 12% plus synthetic amino acids during the growing phase and of 58% when reducing the dietary CP level in feed from 14% to 10% plus synthetic amino acids during the finishing phase.

Kendall, et al., (1998) fed a reduced crude protein (12.2% CP) corn-soy diet with synthetic lysine (.41%), methionine (.013%), tryptophan (.03%), and threonine (.039%) to 27 kg pigs for nine weeks and compared to pigs fed a high crude protein corn-soy diet (16.7% CP). Slurry manure contents had a lower pH (.4 units), lower total N (40%) and lower ammonium N (20%) from pigs fed the reduced crude protein diet compared to the slurry manure from pigs fed the high crude protein diet (Table 8). A 40% reduction of aerial ammonia and hydrogen sulfide occurred in the rooms housing the reduced crude protein pigs (Table 9). In addition, total odors were reduced by 30% based upon olfactometry analysis of room air. However, growth rate and feed efficiency of the pigs fed the reduced crude protein diet was reduced by 4 to 5% compared to the pigs fed the high crude protein diet. Back fat depth was also increased slightly (.13 cm) in the pigs fed the reduced crude protein diet.

In another research study, (Kendall, et al., 1999), 10% soybean hulls were added to the reduced crude protein diet and compared to the normal crude protein diet. In this study, 60 kg pigs were fed either a normal crude protein diet (12.4% CP) or a reduced crude protein diet (9.7% CP) with fiber. The reduced crude protein diet was supplemented with .372% lysine, .005% tryptophan and .042% threonine. As in the previous study, the slurry manure contents were decreased in pH (.3 units), total N (23%) and ammonium N (29%). Ammonia N was decreased by 40% and hydrogen sulfide was reduced by 26.5% in the air of the room housing the pigs fed the reduced crude protein diet with fiber compared to the room housing the pigs fed the normal crude protein diet (Table 10).

Table 8. Pit Composition

Week 9	PH	% DM	%Total N DMB	%Ammonia DMB	%Phosphorus DMB	%Potassium DMB
	Week 9 collection					
HCP[a]	7.6	1.43	20.8	15.9	4.34	6.93
RCP[b]	7.3	2.17	15.9	12.7	4.93	4.79
Significance P<	.008	.07	.025	.07	.02	.01
CV	2.6	49.3	25.7	33.9	15.4	25.7

[a] HCP = High crude protein diet
[b] RCP = Reduced crude protein diet

Table 9. Odor/Gases

	Week 9 collection				
	4 hr. Ammonia conc. (ppm)	Dilution Ratio (Fresh:Sample)	Ammonia (ppm)	Hydrogen Sulfide (ppm)	Blood Urea N (mg/dl)
HCP[a]	33.6	663	23.7	1.41	11.5
RCP[b]	17	472	11.3	.93	4.4
Significance P<	.026	NS	.023	.008	.0001
CV	40.2	42.4	24.1	21.1	30.9

[a] HCP = High crude protein diet
[b] RCP = Reduced crude protein diet

Table 10. Odor and gas analysis.

			Week 9 collection	
	4 hr ammonia conc. (ppm) Week 3	Week 9	Dilution ratio (Fresh:Sample)	H_2S (ppm)
HCP[a]	13.6	21.3	533.2	.36
RCPF[b]	12.7	12.5	500.1	.25
Significance	NS	.03	NS	.02
CV	11.7	17.8	12.8	19.3

[a] HCP = High crude protein diet
[b] RCPF = Reduced crude protein diet with 10% soybean hulls.

In two replicate trials, the pig growths were similar between the two diets. In two additional replicate trials, pigs fed the normal crude protein diets gained faster than the pigs fed the reduced crude protein plus fiber diet, principally related to feed intake being reduced by 6% in pigs fed the reduced protein diet. However, in a subsequent study, when additional synthetic amino acids were added to the diet, gilts performed similar to those gilts fed the control diet including carcass quality and yield. This indicates that there may have been too great of a dietary reduction in amino acids in the previous trials.

A group feeding experiment was conducted by Hill, et al, (2001) with 200 grow-finish pigs (initial BW=92.3 kg) to further evaluate dietary crude protein reduction of swine diets to reduce aerial pollutants and nutrient excretion. The diets consisted of either a control, corn-soybean diet (13.1% CP, .52% true ileal digestible lysine for the barrows and 14.2% CP, .59% true ileal digestible lysine for the gilts) or a reduced CP diet with supplemental synthetic amino acids (9.7% CP, .52% true ileal digestible lysine for the barrows and 10.6% CP, .59% true ileal digestible lysine for the gilts). Aerial ammonia concentration, hydrogen sulfide, and detection threshold of odor samples were taken at wk 2 and 4 from both room and exhaust air. Pigs fed control or low crude protein diets had similar overall average daily gain (790 vs. 784 g/d), overall gain:feed (.304 vs. .297), and average daily feed intake (2601 vs. 2649 g/d). Pigs fed low crude protein diet had greater wk 4 loin depth (57 vs. 55 mm; $P<.09$), numerically higher backfat thickness (17.9 vs. 16.9 mm) and greater total loin depth increase (5.0 vs. 3.1 mm; $P<.02$). By wk 4, there was a 60.4% reduction in aerial ammonia concentration ($P< .04$) from room air and 52.2% reduction in the exhaust air ammonia concentration (13.4 vs 28.1 ppm; $P< .0003$) when pigs were fed low crude protein diets. At wk 4, the stored manure from pigs fed low crude protein diets had 29.8% less total N ($P< .0001$), 30.6% lower ammonium N ($P< .0001$), 35.8% less total N accumulation in the manure ($P<.01$), and a lower manure pH (7.25 vs. 7.61; $P<.0001$). It is clear from these studies that amino acid balanced (correct ratios and concentrations) diets with lower intact crude protein levels are effective at reducing aerial ammonia, manure N, and manure pH. In addition, if adequate amino acid levels are included in the diet, growth performance is comparable to a diet without synthetic amino acids.

Fermentable Carbohydrate

Another possibility to reduce emission of ammonia would be to alter the ratio of N excretion in urine and feces by addition of fermentable carbohydrates. By reducing the N excretion in urine as urea and shifting the N excretion more into the feces in the form of bacterial protein, ammonia volatilization can be reduced. Complex carbohydrates such as β-glucans, and other non-starch polysaccharides (NSP) can influence endogenous N excretion at the terminal ileum and microbial fermentation in the large colon resulting in increased bacterial protein production. Manure from pigs fed cellulose and other nonstarch polysaccharide sources (sugar beet pulp, soybean hulls,) in the pig's diet reduced ammonia emissions, pH of urine, feces and slurry, and changed the composition of N excretion in feces and urine.

Growing barrows were fed low CP diets with synthetic amino acids and two sources of fiber to determine odors and nutrients from fresh manure and manure stored in anaerobic systems (Hankins, et al., 1998). Dietary treatments included: (1) Diet I: a standard 15% crude protein corn-soy diet with 0.75% total lysine; (2) Diet II: a 11% crude protein corn-soy diet with 0.39% crystalline lysine (.76% total Lys), 0.05% methionine (.25% total Met), 0.05% tryptophan (.15% total Trp) and 0.11% threonine (.51% total Thr) added; (3) Diet III: Diet II with 10% soybean hulls, or (4) Diet IV: Diet II with 10% dried sugar beet pulp. Total collections of feces and urine were blended for fresh manure analyses and used in model anaerobic pit incubations.

The lower CP diet with and without the addition of fiber reduced the pH of fresh manure (Table 11). Ammonia N in fresh manure was decreased 31%, 55% and 47% with the lower CP, lower CP plus soybean hulls or dried sugar beet pulp diets, respectively. There was 35% less ammonia N excretion in fresh manure when the reduced CP diet was fed with soybean hulls as a fiber source as compared to the reduced CP diet alone. There was a 38%, 50% and 42% reduction in total N excretion in fresh manure with the lower CP, the lower CP plus soybean hulls and the lower CP plus dried sugar beet pulp diets, respectively. There were no significant effects on VFA in fresh manure, however, there was a trend towards more acetic acid and total VFA production in fresh manure when fiber was added to the diet (Table 12). Similar responses were observed in a similar companion study by Shriver, et al. (2002).

Table 11. Effect of diet on ammonium nitrogen (NH_4-N), total nitrogen (TKN), dry matter (DM) and pH in fresh and stored manure.

Diet (% CP)*	pH	DM	NH_4-N	NH_4-N	TKN	TKN
		%	mg/L	%DM	g/L	%DM
Fresh manure						
Standard (15)	8.4^a	13.1	5841^a	4.9^a	11.9^a	10.4^a
Syn. AA (11)	7.3^b	17.2	5118^{ab}	3.4^b	10.4^b	6.5^b
AA+SBH (11)	6.8^b	18.3	3892^b	2.2^c	9.3^b	5.2^b
AA+DSBP (11)	7.1^b	17.1	4279^b	2.6^{bc}	9.9^b	6.0^b
SEM	.1	1.1	343	.3	.4	.6
Stored manure						
Standard (15)	8.4	4.7	4171^a	8.7^a	5.3^a	11.2^a
Syn. AA (11)	8.1	4.1	2623^b	6.4^b	3.2^b	7.9^b
AA+SBH (11)	7.9	4.8	2458^b	5.3^b	3.5^b	7.6^b
AA+DSBP (11)	7.9	5.0	1588^b	3.1^c	3.0^b	6.0^b
SEM	.2	.3	359	.6	.4	.6

* Diet I: Standard (Std) 15% CP; Diet II: 11% CP with synthetic amino acids (AA); Diet III: Diet II with 10% soybean hulls; Diet IV: Diet II with 10% dried sugar beet pulp.
[a,b] Different letter superscripts in a column is significant (P <.05).

Table 12. Effect of diet on volatile fatty acid (VFA) in fresh and stored manure (mmol/L).

Diet (%CP)*	Ac	Pr	iBu	Bu	IV	V	Total
Fresh manure							
Std (15)	51	19	1.1	11	1.26	3.2	86
Syn. AA (11)	56	24	1.4	12	1.49	4.0	100
AA+SBH (11)	78	28	1.4	15	0.92	4.4	128
AA+DSBP (11)	65	23	1.5	12	1.41	2.3	105
SEM	7	3	.1	1.3	.2	.5	12
Stored manure							
Std. (15)	87	13	2.3	7	4.5	1.9	115
Syn. AA (11)	64	14	1.8	11	2.6	2.7	98
AA+SBH (11)	71	15	2.6	10	2.9	2.8	103
AA+DSBP (11)	49	8	2.1	4	2.5	1.1	67
SEM	7	2	.2	1	.3	.2	10

* Diet I: Standard (Std) 15% CP; Diet II: 11% CP with synthetic amino acids (AA); Diet III: Diet II with 10% soybean hulls; Diet IV: Diet II with 10% dried sugar beet pulp.
[a,b] Different letter superscripts in a column is significant (P <.05).

Table 13. Effect of diet on room odor and gases at week 6

	Control	Soy Hulls	CV	Significance
4hr. Ammonia Conc. (ppm)	13.05	10.38	20.21	.017
Detection Threshold	2424.13	2162.5	38.58	NS
Ammonia (ppm)	4.00	3.63	23.36	NS
Hydrogen Sulfide (ppm)	1.03	0.701	20.99	.003

Table 14. Effect of diet on volatile fatty acids (VFA) in stored manure at week 6.

	VFA, mmol/L						
	Ac	Pr	IB	B	iV	V	Total
Control	57.7	16.7	2.1	16.8	2.0	1.7	97.0
Control+SH[a]	77.1	23.3	2.5	20.3	2.4	2.4	128.0
Significance *P*<	.0004	.0003	.013	.036	.043	.004	.0008
SEM	2.84	0.94	0.11	1.05	0.12	0.14	4.91

[a] Control Diet with 10% soy hulls

Similar treatment effects were observed with anaerobically stored manure. There was a significant reduction in ammonia and total N with the lower CP diet and synthetic amino acids either alone (37% and 26% reduction for ammonia and 40% to 29% reduction for total N on a wet and DMB, respectively) or with 10% soybean hulls (41% and 39% reduction for ammonia and 34 % and 32% reduction for total N on a wet and DMB, respectively) or 10% dried sugar beet pulp (62% and 64% reduction for ammonia and 43 % and 46% reduction for total N on a wet and DMB, respectively) (Table 11). In addition, on a dry matter basis, sugar beet pulp further reduced ammonia N compared to the other treatments. VFA tended to be lower in stored manure from pigs fed the sugar beet pulp diet compared to the other diets (Table 12). The addition of soybean hulls and sugar beet pulp reduced benzene, dimethyl disulfide, 2,2-dimethyl hexane and hexane in stored manure. The lower CP diet also reduced the previously stated VOC in stored manure as well as methyl pentane.

In a group feeding study, 150 grow-finish pigs (initial BW=85.3 kg) were used to evaluate the inclusion of soybean hulls in swine diets to reduce aerial pollutants and alter manure composition (DeCamp, et al., 2001). Diets were split-sex fed and consisted of either a corn-soybean meal based control (C) or the control diet with the addition of 10% soybean hulls and 3.4% supplemental fat (SH) (all diets=3370 Kcal ME/kg; barrows 12.0% CP, 0.53% dLys) gilts 12.7% CP, 0.57% dLys.

Pigs fed SH diets had greater overall ADG (905 vs 859 g/d; P<.03) and tended to have higher G:F (0.326 vs 0.310; P<.09) with no difference in ADFI. Pigs fed SH had greater adjusted backfat (113 kg BW) at wk 6 (15.8 vs 14.7 mm; P<.001) than C pigs. There was a 20% reduction in aerial ammonia concentrations (P<.02), a 32% reduction in hydrogen sulfide (P<.003) and an 11% reduction in odor detection threshold when pigs were fed SH diets. Manure pH was decreased (7.12 vs 7.26; P<.03) and individual manure VFA concentrations were increased, with total manure VFA concentrations increasing by 32% (P<.001) when pigs were fed SH. The stored manure from pigs fed SH diets had 21% greater total N (22.5 vs 18.6 kg; P<.02) and an 8% increase in ammonium N (18.3 vs 16.9 kg; P<.05). This increased manure N should be in a more stable microbial protein form with less volatile emissions and provide a reduced environmental runoff potential. However, the impact was greater when low crude protein and synthetic amino acid diets included fiber versus no crude protein reduction.

In an attempt to use a combination of several dietary techniques, Kendall, et al. (2001) conducted a study with one-hundred and eighty grow-finish pigs. In the first experiment, diets consisted of either a control, corn-soybean diet (11.5% CP, .60% Lysine; Lys)

Table 15. Effect of soyhulls in the diet on manure composition

	Control	Soy Hulls	CV	Significance
Manure Pit Volume (gal)				
Initial (as is)	840	840	--	--
Final (as is)	3209.6	2849.6	11.2	.10
Manure Drymater, %				
Initial	0.26	0.28	4.2	.07
Final	0.97	1.65	9.7	.0001
TN				
Initial (ppm)	510.2	438.5	9.7	.03
Final (ppm)	1681.3	2226.8	9.8	.001
Total pit accumulation, lb	41.0	49.7	11.5	.02
Ammonia				
Initial (ppm)	340.3	321.8	2.6	.006
Final (ppm)	1495.5	1817.2	7.3	.002
Total pit accumulation, lb	37.3	40.4	6.0	.05
Phosphorous				
Initial (ppm)	209.5	186.2	19.9	.33
Final (ppm)	500.7	606.5	5.8	.0005
Total pit accumulation, lb	11.9	12.6	15.1	.49
pH				
Initial	8.21	8.26	2.0	.69
Final	7.26	7.12	1.3	.03
Change	-0.93	-1.15	20.2	.19

or a reduced CP diet formulated with high-available phosphorus corn, 272 units of phytase, 5% soybean hulls and a reduced mineral sulfate trace mineral premix (8.25% CP, .57% Lys; HRP) with supplemental synthetic amino acids. In the second experiment, barrows were fed the same diets as the first experiment, but two additional diets were formulated for gilts; control (12.6%CP, .63% Lys) and HRP (9.35% CP, .60% Lys) with supplemental synthetic amino acids. All diets were isocaloric and equal in digestible Lys. Pigs fed control diets in the first experiment were heavier, had higher average daily gain (824 vs. 735 g/d; $P < .004$), were more efficient, had greater loin depths at week 6, less accumulation of backfat. In contrast, the pigs fed control diets in the second experiment were nearly identical to pigs fed HRP diets in every respect. By week 6, there was a 48.7% reduction in aerial ammonia concentrations ($P < .03$) from room air and 49.8% reduction in the exhaust air ($P < .04$) for pigs fed HRP diets. Hydrogen sulfide levels were 48% lower and detention threshold was 37% lower at week 6 in room air where HRP diets were fed. At week 6, the stored manure from pigs fed HRP diets had 26.9% less total-N, 29.5% lower ammonium-N, 51.7% less excreted P and had a lower pH. The manipulation of the HRP diet was successful at reducing aerial ammonia concentrations, hydrogen sulfide, detection threshold, manure N, P and pH with comparable performance in the pigs as long as adequate amino acid levels were included in the diet.

Sulfur Manipulation

Shurson et al. (1999) stated that feeding nursery pigs low sulfur diets can potentially reduce hydrogen sulfide and other odors from nursery facilities. Growing-finishing gilts were fed different levels of sulfur-containing amino acids and sulfur mineral

Table 16. Effect of diet on pH, and nitrogen components in fresh and stored manure[1]

Diet (%CP)[3]	pH	DM	NH_4-N	NH_4-N	TKN[2]	TKN[2]
		%	mg/L	%DM	mg/L	%DM
Fresh manure						
I: Std. (13)	8.2[a]	11.2	5912	6.08[a]	1.26	13.08[a]
II: AA (8)	7.1[b]	15.4	4813	3.37[b]	1.17	8.02[b]
III: AA (8)	6.9[b]	15.8	4411	2.94[b]	1.07	7.20[b]
IV: Std. (13)	8.2[a]	10.7	5397	5.47[a]	1.32	14.27[a]
SEM	.2	1.5	522	.6	.1	.6
Stored manure						
I: Std. (13)	8.0	6.0	6196[a]	9.08[a]	8653[a]	12.7[a]
II: AA (8)	7.9	6.0	3771[b]	6.40[ab]	5736[b]	9.6[ab]
III: AA (8)	7.3	6.0	3203[b]	4.85[b]	5223[b]	8.0[b]
IV: Std. (13)	7.9	5.4	6161[a]	9.97[a]	8822[a]	14.0[a]
SEM	.2	.3	655	1.3	808	1.5

[1]Different letter superscripts within a column are significant ($P<0.05$).
[2]TKN = Total Kjeldahl nitrogen.
[3]Diet I:13% CP with ferrous sulfate and copper sulfate; Diet II:8% CP with synthetic AA and ferric chloride and copper oxide, Diet III:8% CP with synthetic AA and ferrous sulfate and copper sulfate; Diet IV:13% CP with ferric chloride and copper oxide.

sources to determine odors and nutrients from fresh manure and manure stored in anaerobic systems (Kendall et al., 2001). The pH, ammonia N and total N in fresh manure was lower for pigs fed low CP-amino acid supplemented diet compared to the standard commercial diet. In addition, hydrogen sulfide emission was less (by up to 48%) with the low crude protein and low sulfur mineral diet.

Growing-finishing gilts (54 kg) were fed different levels of sulfur-containing amino acids and sulfur mineral sources to determine odors and nutrients from fresh manure and manure stored in anaerobic systems (Sutton, et al., 1998b). Dietary treatments included (1) Diet I: a standard 13% CP corn-soy diet with .54% total methionine + cystine; .6% total lysine; .16% tryptophan; .53% threonine with 225 ppm ferrous sulfate and 250 ppm copper sulfate; (2) Diet II: an 8% CP corn-soy diet with synthetic amino acids; .43% L-lysine (.6% total lysine), .20% DL-methionine (.36% total methionine), .02% L-tryptophan (.11% total tryptophan, and .075% L-threonine (.41% total threonine) 355 ppm ferric chloride and 80 ppm copper oxide, (3) Diet III: diet II with 225 ppm ferrous sulfate and 250 ppm copper sulfate, and (4) Diet IV: Diet I with 355 ppm ferric chloride and 80 ppm copper oxide.

The pH, ammonia N and total N in fresh manure was lower for pigs fed the 8% CP amino acid supplemented diet compared to the 13% CP standard diet. Between the 8% CP diets, the diet with ferric chloride and copper oxide was higher in nitrogenous compounds and pH (Table 16) as compared to the sulfur-containing mineral sources in diet III. Similar results were observed with the long-term anaerobic storage of the manure from the pigs fed the 8% CP amino acid supplemented diet having lower ammonia and total N than the 13% CP diets. Ammonia N and total N reduction with the 8% CP diets averaged 60% and 46% respectively, compared to the 13% CP diets. The lowest pH, ammonia, and total N was observed with the 8% CP diet with the sulfur-containing minerals. Increasing the biological availability of sulfur amino acids and other amino acids by using synthetic amino acid sources in the diet while simultaneously reducing the level of these essential and the non-essential amino acids in the diet reduced N excretion, ammonia volatilization, sulfur-containing VOC and manure odors.

Microbial Manipulation

Attempts have been made to isolate and identify the microbial populations in the digestive systems of pigs that control or are involved in the creation of odors. Ward et al. (1987) isolated an obligate anaerobe of the Lactobacillus sp. that decaboxylated p-hydroxyphenylacetic acid to 4-methylphenol (p-cresol) in swine feces. In a review, Yokoyama and Carlson, (1979) reported that several *Clostridia* sp., *E. coli* and *Bacteroides thetaiotaomicron* can be involved with indole and skatole production. Compounds such as oligosaccharides (fructooligosaccharides, mannoligosaccharides, sucrose thermal oligosaccharide carmel, inulin, arabinogalactan, galactan), dairy byproducts (lactulose, lactitol, lactose, whey), and organic acids (propionic, fumaric, citric) have been added to manipulate the microflora populations.

Fructooligosaccharides have been shown to alter VFA patterns in the lower GIT (reduce proportion of acetate and increase the proportion of propionate), reduce total aerobes, predominantly coliforms, increase bifidobacteria (Houdijk et al., 1999) and reduce odorous compounds from swine manure (Hidaka et al., 1986). Inulin from Jerusalem artichoke fed at 3 and 6% of the pig's diet tended to reduce odors to be less sharp and pungent and with less skatole. In earlier work, antibiotics (chlortetracycline, sulfamethazine, penicillin) fed to pigs reduced urinary excretion of p-cresol, the predominant malodorous metabolite in swine manure (Yokoyama et al., 1982). Lincomycin sulfate did not affect p-cresol excretion. Recent work by Japanese researchers, have shown that tea polypheonols in swine diets lowered the production of ammonia, phenol, p-cresol, ethylphenol, indole and skatole in swine feces (Terada et al., 1993). Also, the tea polypheonols were shown to significantly reduce certain pathogenic species *(Mycoplasma pneumonia, Staphylococcus aureus,* and *Clostridium perfringens;* Hara and Ishigami, 1989; Chosa et al., 1992).

In a review (Miner, 1975), several studies showing attempts to reduce odors by feeding various microbial organisms or physical additives to pigs were not successful. In three studies, dry *Lactobacillus acidophilus* (10 g/d), liquid *L. acidophilus* (300-350 ml/d), whole milk (300 ml/d), yeast (2 or 5%), charcoal (2 or 5%), and sagebrush (5%) were added to weanling pig diets. There were no differences in olfactometry measurements, except for a reduced odor score with 5% charcoal added to the diet. However, when VOC concentrations (peak height ratios) were analyzed, there was a significant reduction in skatole and indole in manure of the young pigs after a 2-wk study with yeast (2%) and dry *L. acidophilus* (10 g/d) in the diet. These reductions in skatole and indole continued through the third wk of incubation.

Physical Characteristics

Several studies have been conducted showing the effects of reducing the pH of manure and ammonia emission by adjusting the dietary electrolyte balance, reducing urea excretion or increased volatile fatty acid production. Canh et al. (1997) showed that increasing the NSP content and decreasing the electrolyte balance (dEB) of the diet reduced the pH of pig slurry. Inclusion of 30% sugar beet pulp (with 31.2% NSP) reduced the pH of slurry by 0.44 to 1.13 pH units lower than a by-product diet (with 18.2% NSP), grain-based diet (with 13.8% NSP) and a tapioca-based diet (with 13.5% NSP). The decreased dietary electrolyte balance (expressed as mEq Na + K - Cl) in the diet reduced the pH of urine and subsequent slurry. Canh et al. (1996) and Mroz et al. (1996) showed that dietary calcium salts and electrolyte balance significantly influenced urinary pH and subsequent pH and ammonia emission from pig slurry. Mroz et al. (1997) showed that increasing the levels of calcium benzoate (2, 4, 8 g/kg feed) in the diet of sows significantly reduced pH of urine from 7.7 to 5.5 and reduced ammonia emissions up to 53%. In nursery diets, Colina et al. (2001) observed a significant reduction in ammonia emissions in the rooms housing nursery pigs. However, feed intakes were lowered and performance was depressed when 1.96% calcium chloride was added to the diet. Van Kempen et al. (2001) showed the benefits of using adipic acid in pig diets to reduce pH and ammonia emissions but did not improve lysine utilization in the pig.

Bentonite and zeolite materials have been tested to bind ammonia in manure and reduce release of ammonia to the atmosphere. Kreiger et al. (1993) did not find any affect of feeding a naturally processed clinoptilolite on ammonia emissions from swine manure. Pilot studies in Canada showed a 21% reduction in ammonia N in the room of pigs fed 5% zeolite (tektosilicate). Zeolites can also absorb phenols. However, when these products are fed to the pig there has been little effect on manure odor. Sarsaponin extracts from the *Yucca schidigera* plant has been incorporated in the pig's diet as a growth promotant and to reduce ammonia emission from manure. Ammonia emission was significantly suppressed by 55.5% in fresh manure tested in an incubation trial from pigs fed the sarsaponin extract. However, Kemme et al. (1993) conducted incubation trials with manure and did not verify the same response to ammonia inhibition and found that 6000 mg/kg of the extract was necessary for maximal suppression of ammonia from urea. Recent work by Colina et al. (2001) has shown that addition of *Yucca schidigera* to nursery pig diets reduced ammonia emissions in nursery rooms.

Geisting and Easter (1986) summarized studies incorporating organic acids (citric, hydrochloric, propionic, fumaric, and sulfuric) at dietary levels of 1 to 4% showing variable results in pH effects on digesta and growth effects on swine. One mode of action suggested for fumaric acid was as a protein sparing effect in the metabolism of swine (Giesting and Easter, 1985). Risely et al. (1992) also showed that addition of fumaric or citric acids (1.5%) had very little effect on pH, volatile fatty acids, or chlorine concentrations of intestinal contents of swine. Thus, odor control would not be affected by lowered pH or volatile fatty acid production. The initial buffering capacity of the diet along with buffering capacity of the intestinal contents in the digestive tract of the pig may have an influence on the final pH. Microbial concentrations of total anaerobes, *Lactobacillus sp*, *Clostridia sp*, and *E. coli* were not affected by the organic acids.

Implications

Modifying the pig's diet to reduce odors is feasible and practical. Reducing the crude protein level and supplementing with synthetic amino acids, addition of low levels (<10%) of fermentable nonstarch polysaccharides, and addition of pH and buffering feed ingredients have promise. Feed management practices of formulating diets to meet the lean tissue accretion levels of the specific genetic lines, phase feeding, split-sex feeding and minimizing feed wastage will assist in reducing nutrient excretions. Manipulation of the microflora in the pig's digestive tract shows indication of some influence on odors, however, work in this area has not received as much research attention. Techniques to increase the availability and retention of nutrients can reduce excretions of compounds commonly causing odors. Implementation of several of these technologies and practices often in combinations have the potential of reducing ammonia and hydrogen sulfide emissions by 30 to 50% and reduce odors by 30% at very little cost to the producer. Economics is still a major issue determining if certain manipulation technologies will be adopted. Research to fine-tune these altered diets for commercial production systems is needed for encouraging implementation.

References

Armstrong, T. A., C. M. Williams, J. W. Spears and S. S. Shiffman. 2000. High dietary copper improves odor characteristics of swine waste. J. Anim. Sci. 78:859-864.

Canh, T. T., A. J. A. Aarnink, Z. Mroz, and A. W. Jongbloed. 1996. Influence of dietary calcium salts and electrolyte balance on the urinary pH, slurry pH and ammonia volatilization from slurry of growing-finishing pigs. ID-DLO Rept. 96-51. 39 pp.

Canh, T. T., M. W. A. Verstegen, A. J. A. Aarnink and J. W. Schrama. 1997. Influence of dietary factors on nitrogen partitioning and composition of urine and feces in fattening pigs. J. Anim. Sci. 75: 700-706.

Chosa, H., M. Toada, S. Okubo, Y. Hara and T. Shimamura. 1992. Antimicrobial and microbicidal activities of tea and catechins against Mycoplasma. J. Japanese Assoc. Infectious Dis. 66:606-611.

Colina, J. J., A. J. Lewis, P. S. Miller and R. L. Fisher. 2001. Dietary manipulation to reduce aerial ammonia concentrations in nursery facilities. J. Anim. Sci. 79:3096-3103.

DeCamp, S. A., B. E. Hill, S.L. Hankins, D. C. Kendall, B.T. Richert, A.L. Sutton, D.T. Kelly, M.L. Cobb, D.W. Bundy, and W.J. Powers. 2001. Effects of soybean hulls in a commercial diet on pig performance, manure composition, and selected air quality parameters in swine facilities. J. Amim. Sci.

Giesting, D. W. and R. A. Easter. 1985. Response to starter pigs supplementation of corn soybean meal diets with organic acids. J. Anim. Sci. 60:1288

Geisting, D. W. and R. A. Easter. 1986. Acidification status in swine diets. Feed Management. 37: 8, 10, 53.

Gralapp, A. K., W. J. Powers, D. S. Bundy. 2001. Comparison of olfactometry, gas chromatography, and electronic nose technology for measurement of indoor air from swine facilities. Trans. ASAE. 44: 1283-1290.

Hankins, S.L., A.L. Sutton, J.A. Patterson, B.T. Richert, A.J. Heber, D.T. Kelly, K.B. Kephart, R. Mumma, E. Bogus, and S.D. Carter. 1998.

Reduction in Odorous Compounds in Pig Manure Through Dietary Fiber Manipulation. J. Anim. Sci.

Hara, Y. and T. Ishigami. 1989. Antibacterial activities of polyphenols against food borne pathogenic bacteria. Nipppon Shokuhin Gakkaishi 36:996-999.

Hidaka, H., T. Eida, T. Takizawa, T. tokanaga and Y. Tashiro. 1986. Effect of fructooligosacchairdes on intestinal flora and human health. Bifidobact. Microflora 5:37-50.

Hill, B. E., S. L. Hankins, D. C. Kendall, B. T. Richert, A. L. Sutton, D. T. Kelly, M. L. Cobb, D. W. Bundy and W. J. Powers. 2001. Effects of soybean hulls in a commercial diet on pig performance, manure composition, and selected air quality parameters in swine facilities. J. Anim. Sci. 79:252. (Abstract)

Hobbs, P. J., T. H. Misselbrook and B. F. Pain. 1995. Assessment of odours from livestock wastes by photoionization detector, an electronic nose, olfactometry and gas chromatography-mass spectorometry. J. Agric. Eng. Res. 60:137-144.

Hobbs, P. J., B. F. Pain, R. M. Kay and P. A. Lee. 1996. Reduction of odorous compounds in fresh pig slurry by dietary control of crude protein. J. Sci. Food Agric. 71:508-514.

Houdijk, J. G. M., M. W. Bosch, S. Tamminga, M. W. A. Verstegen, E. B. Berenpas and H. Knoop. 1999. Apparent ileal and total tract nutrient digestion by pigs as affected by dietary nondigestible oligosaccharides. J. Anim. Sci. 77:148-158.

Kemme, P. A., A. W. Jongbloed, B. M. Dellaert and F. Krol-Kramer. 1993. The use of a Yucca Schidigera exctract as 'urease inhibitor' in pig slurry. Proc. First Inter. Symp. Nitrogen Flow in Pig Production and Environ. Consequences. pp. 330-335. Wageningen, NL

Kendall, D. C., K. M. Lemenager, B. T. Richert, A L. Sutton, J. W. Frank and B. A. Belstra. 1998. Effects of intact protein diets versus reduced crude protein diets supplemented with synthetic amino acids on pig performance and ammonia levels in swine buildings. J. Anim. Sci. 76(Suppl. 1):173. (Abstract)

Kendall, D. C., B. T. Richert, A. L. Sutton, J. W. Frank, S. A.DeCamp, K. A. Bowers, D. Kelly, M Cobb. 1999. Effects of fiber addition (10% soybean hulls) to a reduced crude protein diet supplemented with synthetic amino acids verses a standard commercial diet on pig performance, pit composition, odor and ammonia levels in swine buildings. J. Anim. Sci. 77 (Suppl):176 (Abstract)

Kendall, D. C., B. T. Richert, K. A. Bowers, S. A. DeCamp, C.T. Herr, T. E. Weber, M. Cobb, D. Kelly , A. L. Sutton, D. W. Bundy, and W. J. Powers. 2001. Effects of Dietary Manipulation on Pig Performance, Manure Composition, Aerial Ammonia, Hydrogen Sulfide, and Odor Levels in Swine Buildings. J. Anim. Sci. 79 (Suppl): 59 (Abstract)

Kreiger, R. J. Hartung and A. Pfeiffer. 1993. Experiments with a feed additive to reduce ammonia emissions from pig fattening housing – preliminary results. Proceedings of the First International Symposium. Nitrogen Flow in Pig Productin and Environmental Consequences. Wageningen, Netherlands. June 8-11. pp. 295-300.

Miner, J. R. 1975. Management of odors associated with livestock production. Proc. 3rd Inter. Symp. Livest. Waste, ASAE., pp. 378-380.

Mroz, Z., A. W. Jongbloed, K. Vreman, T. T. Canh, J. Th. M. van Diepen, P. A. Kemme, J. Kogut and A. J. A. Aarnink. 1996. The effect of different cation-anion supplies on excreta composition and nutrient balance in growing pigs. ID-DLO Rep. 96.028.

Mroz, Z., W. Krasucki and E. Grela. 1997. Prevention of bacteriuria and ammonia emission by adding sodium benzoate to diets for pregnant sows. Ann. Mtg. EAAP. Vienna, Austria. August 25-28.

National Research Council. 1998. Nutrient Requirements of swine. 10th rev. ed. National Academy Press, Washington, DC.

Risley, C. R., E. T. Kornegay, J. D. Lindemann, C. M. Wood and W. N. Eigel. 1992. Effect of feeding organic acids on selected intestinal content measurements at varying times postweaning pigs. J. Anim. Sci. 70(1): 196-206.

Shriver, J. A., S. D. Carter, A. L. Sutton, B. T. Richert, B. W. Senne and L. A. Pettey. 2002. Effects of adding fiber sources to reduced crude protein, amino acid-supplemented diet on nitrogen excretion, growth performance, and carcass traits in finishing pigs. J. Anim. Sci. (In press).

Shurson, J., M. Whitney and R. Nicolai. 1999. Manipulating diets may reduce hydrogen sulfide emissions. Feedstuffs. 25 January:12-17.

Sutton, A. L., K. B. Kephart, J. A. Patterson, D. T. Kelly, E. Bogus, D. D. Jones, A.J. Heber and J. Nielsen. 1998a. Manipulating Nitrogen in Pig Diets to Reduce Manure Nitrogen Excretion and Odors. Swine Day Report 147-155.

Sutton, A. L., J. A. Patterson, O. L. Adeola, B. T. Richert, D. T. Kelly, J. Nielsen, A.J. Heber, K. B. Kephart and E. Bogus. 1998b. Amino Acid and Mineral Manipulation in Pig Diets to Reduce Nitrogen and Odors in Pig Manure. Swine Day Report 165-174.

Sutton, A. L., K. B. Kephart, M. W. A. Verstegen, T. T. Canh and P. J.. Hobbs. 1999. Potential for reduction of odorous compounds in swine manure through diet modification. J. Anim. Sci. 77:430-439.

Sutton, A. L., B. T. Richert, S. L. Hankins, S. A. DeCamp and A. L. Carroll. 2001. Potential impact of ractopamine on environmental stewardship. J. Anim. Sci. 79:238.

Terada, A., H. Hara, S. Nakajyo, H. Ishikawa, Y. Hara, K. Kukai, K. Kobayashi and T. Mitsouka. 1993. Effect of supplemetns of tea polyphenols of the caecal flora and caecal metabolites of chicks. Microb. Ecol. Health and Dis. 6:3-9.

Turner, L. W., G. L.Cromwell, T. C. Bridges, S. Carter and R. S. Gates. 1996. Ammonia (NH_3) emission from swine waste as influenced by diet manipulation. Proc. *1st Inter. Conf. Air Pollution from Agr. Operations*. Pp. 453-458. Kansas City, Missouri. February 7-9.

Van Kempen, T. A. T. G. 2001a. Dietary adipic acid reduces ammonia emission from swine excreta. J. Anim. Sci. 79:2412-2417.

Van Kempen, T. A. T. G., W. J. Powers and A. L. Sutton. 2002. Technical note: Fourier transform infrafred (FTIR) spectroscopy as an optical nose for predicting odor sensation. J. Anim. Sci. 80:1524-1527.

Ward, L. A., K. A. Johnson, I. M. Robinson and M. T. Yokoyama. 1987. Isolation from swine feces of a bacterium which decarboxylates p-hydroxyphenylacetic acid to 4-methylphenol (p-cresol). Appl. Environ. Micro. 53:189-192.

Yokoyama, M. T. and J. R. Carlson. 1979. Microbial metabolites of tryptophan in the intestinal tract with special reference to skatole. Am. J. Clin. Nutr. 32:173-178.

Yokoyama, M. T., C. Tabori, E. R. Miller and M. G. Hogberg. 1982. The effects of antibiotics in the weanling pig diet on growth and the excretion of volatile phenolic and aromatic bacterial metabolites. Am. J. Clin. Nutr. 34:1417-1424

Impacts of Genetically Modified, Low-Phytate Corn and Soybean Meal and Transgenic Pigs Possessing Salivary Phytase on Phosphorus Excretion

Gary L. Cromwell
Professor
Department of Animal Sciences
University of Kentucky
Lexington, KY 40546

Summary

Addressing the problems of odor and environmental pollution from high levels of nitrogen, phosphorus, and other nutrients in animal manure is one of the major challenges facing animal agriculture. Swine manure is rich in nitrogen and phosphorus. Inappropriate application of manure to crop land can result in negative effects on surface and ground water. Several new technologies are becoming available or will soon be available to assist in reducing phosphorus excretion. Two of these are low-phytate corn and low-phytate soybean meal. Research has shown that the reduced phytate content in these feed ingredients increases the bioavailability of P by several fold and markedly reduces phosphorus excretion when fed to pigs. Transgenic pigs with high levels of salivary phytase also provide a possible biological approach to reducing phosphorus excretion in swine manure.

Introduction

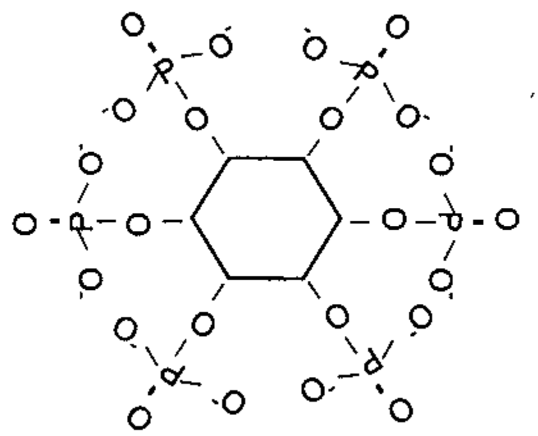
Meeting the environmental challenges in agriculture is one of the major issues facing the animal industry. Beef cattle, dairy cattle, sheep, swine, and poultry produce nearly 160 million metric tons of manure (dry matter basis) annually (Sweeten, 1992; Table 1). Most of the swine and poultry waste is produced in confinement units where the nearby land base often is insufficient to accomodate the waste in an environment-friendly manner. Nitrogen (N) and phosphorus (P) in animal manure can contribute to surface and ground water pollution. In addition, N from manure can contribute to aerial ammonia and other gasses, including those with offensive odors (Turner et al., 1996).

Nitrogen and Phosphorus in Swine Manure

Swine manure is quite high in both N and P (Table 1). The high N content is attributable to several factors. First, swine diets are relatively high in crude protein due to the large amounts of amino acids that are needed to support a high rate of lean growth. Second, the dietary protein is not completely digested as the feed passes through the digestive tract which results in approximately 15 to 20% of the dietary N passing out of the pig in the feces. Third, and probably most important, the pattern of the amino acids that are digested from the protein and absorbed into the bloodstream is far from ideal in comparison with the pattern of amino acids that is needed for growth and other functions. Thus, the N from those amino acids that are in excess of the pig's requirements is converted into urea and excreted in the urine.

The major reason for the high level of P in swine manure is that most of the P in cereal grains and oilseed meals is bound in an organic complex called *myo*-inositol 1,2,3,4,5,6-hexakisphosphate, commonly referred to as phytic acid or phytate (Figure 1). Nelson et al. (1968) showed that 56 to 81% of the P in cereal grains and oilseed meals is in this form (Table 2). In order for animals to utilize the P from

Figure 1. Structure of Phytic Acid



phytate, the phosphate groups must first be enzymatically released from the complex, a process that requires the enzyme, phytase. Unfortunately, pigs and poultry do not have sufficient amounts of phytase in their digestive tract to hydrolyze the P from phytate, so most of the P from the major ingredients in the diet (i.e., grain, soybean meal) is excreted in the feces. In contrast, ruminants utilize phytate quite well because of the abundance of phytase produced by rumen microorganisms.

Nutritional Strategies to Reduce N and P in Swine Manure

There are a number of nutritional strategies that can be used to reduce the concentration of N and P in swine manure (Carter et al., 1996; CAST, 2002). Feeding diets that do not have excessive levels of crude protein (amino acids) is one of the most effective means of reducing N excretion. Another effective way of reducing N excretion is to reduce the dietary protein level and add crystalline amino acids. Research at our station has shown that feeding a diet with 2 percentage points less protein plus 0.15% supplemental lysine is essentially equivalent to a higher protein diet, and will reduce N excretion by 20 to 30% (Cromwell, 1996). Further reductions in dietary protein are possible if the diet is supplemented with additional lysine along with certain other amino acids such as threonine, tryptophan, and methionine. In addition, N excretion can be reduced by using high quality protein sources with good amino acid profiles, by using feed ingredients that have more highly digestible protein, and by formulating diets on an "ideal protein" basis such that those amino acids that exceed the pig's requirements are not excessive.

Similarly, P excretion can be reduced by feeding diets that do not have excessive levels of supplemental P. For example, feeding a diet with 0.2 of a percentage unit more P than needed to growing-finishing pigs (a common practice a few years ago) will result in a 70% increase in P excretion as compared with feeding P levels that meet NRC (1998) standards. The addition of phytase to diets in which the dietary P is reduced is another effective scheme that will reduce P excretion. Studies have shown that 0.1 of a percentage point reduction in dietary P along with phytase supplementation will reduce P excretion by 25 to 35% in growing-finishing pigs (Cromwell et al., 1995).

A relatively new technology that has excellent potential for reducing P excretion is the feeding of cereal grains and oilseed meals with reduced phytate content. The rest of this paper will address these two new crops and review their potential for reducing P excretion by swine.

Low-Phytate Corn

In 1990, Victor Raboy, a USDA plant breeder then at Montana State University, reported the discovery of mutant genes in corn that suppressed the synthesis of phytic acid in the seed without affecting the amount of total seed P (Raboy et al., 1990). As a result, the inorganic P was markedly increased in the germ of the corn kernel (Figure 2).

In 1996, sufficient quantities of corn containing one of these mutant low-phytate gene (*lpa1*) were available for animal testing. This corn contained half as much phytate P (0.10 vs 0.20%) and over three times as much inorganic P (0.18 vs 0.05%) as a near-isogenic conventional corn (Table 3, Figure 3). The starch, protein, amino acids, and other important nutritional traits are not affected by the low-phytate gene. The gene apparently affects only the type of P in the corn grain.

In initial testing at the University of Kentucky using slope-ratio procedures, we found that the P in low-phytate corn was about three to four times more bioavailable for pigs than the P in normal corn (Figure 4). Specifically, the low-phytate gene increased the bioavailability of P from approximately 20% in

Table 1. Quantities of dry manure, nitrogen, and phosphorus excreted annually by livestock and poultry in the United States[a]

Species	Manure (million tons)	Mineral Conc. (%)		Excretion (thousand tons)	
		N	P	N	P
Ruminants					
Beef cattle	96.6	3.96	1.07	3,828	1,029
Dairy cattle	29.1	3.75	0.79	1,091	230
Sheep	1.8	3.89	0.56	70	10
Nonruminants					
Swine	15.5	4.71	2.97	730	460
Poultry	15.4	5.13	1.62	790	250
Total	158.4			6,509	1,979

[a]Adapted from Sweeten (1992).

Table 2. Phytate phosphorus content of some common feed grains, byproducts, and oilseed meals[a]

Feedstuff	Total P %	Phytate P % of total
Barley	0.34	56
Oats	0.34	56
Soybean meal	0.61	61
Corn	0.26	66
Wheat	0.30	67
Grain sorghum	0.31	68
Wheat bran	1.37	70
Cottonseed meal	1.07	70
Wheat middlings	0.47	74
Sesame meal	1.27	81

[a]Adapted from Nelson et al. (1968).

normal corn to over 75% in low-phytate corn (Cromwell et al., 1998). Similar results were reported by Spencer et al. (2000c) using similar procedures and by Veum et al. (2001) using an in vitro procedure.

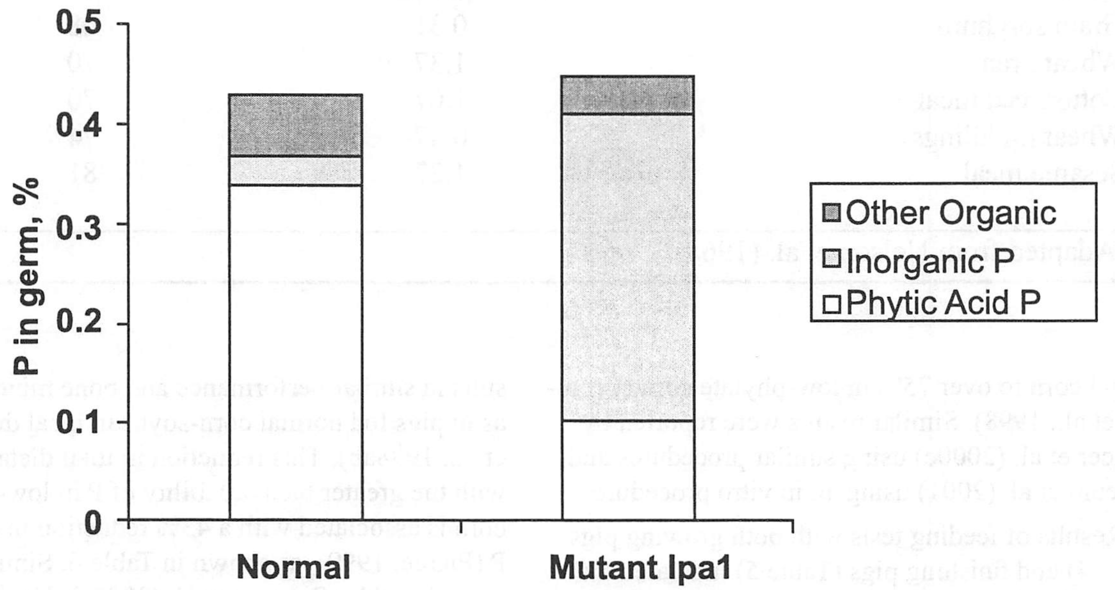
Results of feeding tests with both growing pigs (Table 4) and finishing pigs (Table 5) indicated that feeding pigs low-phytate corn-soybean meal diets containing 0.10 to 0.12% less total P than normal results in similar performance and bone mineralization as in pigs fed normal corn-soybean meal diets (Pierce et al., 1998ab). This reduction in total dietary P along with the greater bioavailability of P in low-phytate corn is associated with a 43% reduction in excreted P (Pierce, 1999), as shown in Table 6. Similar results were found by Spencer et al. (2000c). Veum et al. (2001) and Sands et al. (2001) also reported reduc-

Table 3. Composition of normal and low-phytate corn and normal and low-phytate, low oligosaccharide soybean meal[a]

Item	Normal Corn	Low-Phytate Corn
	%	%
Crude protein	8.50	8.50
Crude fat	2.50	2.74
Calcium	0.01	0.01
Total phosphorus	0.25	0.28
Phytate phosphorus	0.20	0.10
Inorganic phosphorus	0.05	0.18
Amino acids		
Lysine	0.23	0.24
Threonine	0.28	0.28
Tryptophan	0.05	0.05
Methionine	0.15	0.15
Cystine	0.17	0.19
Isoleucine	0.29	0.27
Valine	0.40	0.40

[a]DuPont Speciality Grains, Des Moines, IA. The normal and low-phytate corns were near-isogenic.

Figure 2. Forms of Phosphorus in Germ of Normal and Mutant *lpa1* Corn



Raboy et al, (1990)

Figure 3. Forms of Phosphorus in Normal and Low Phytate Corn

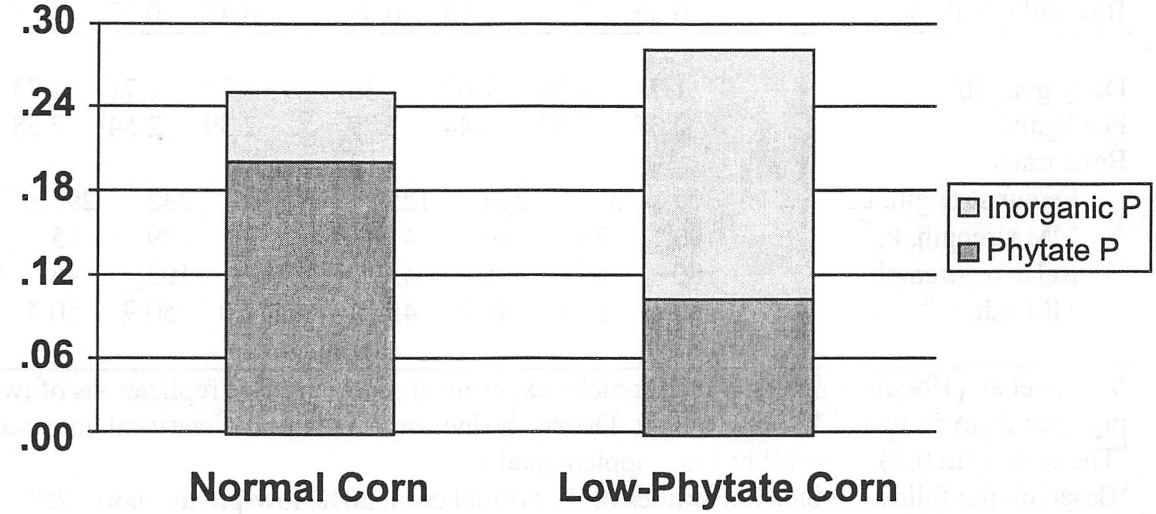
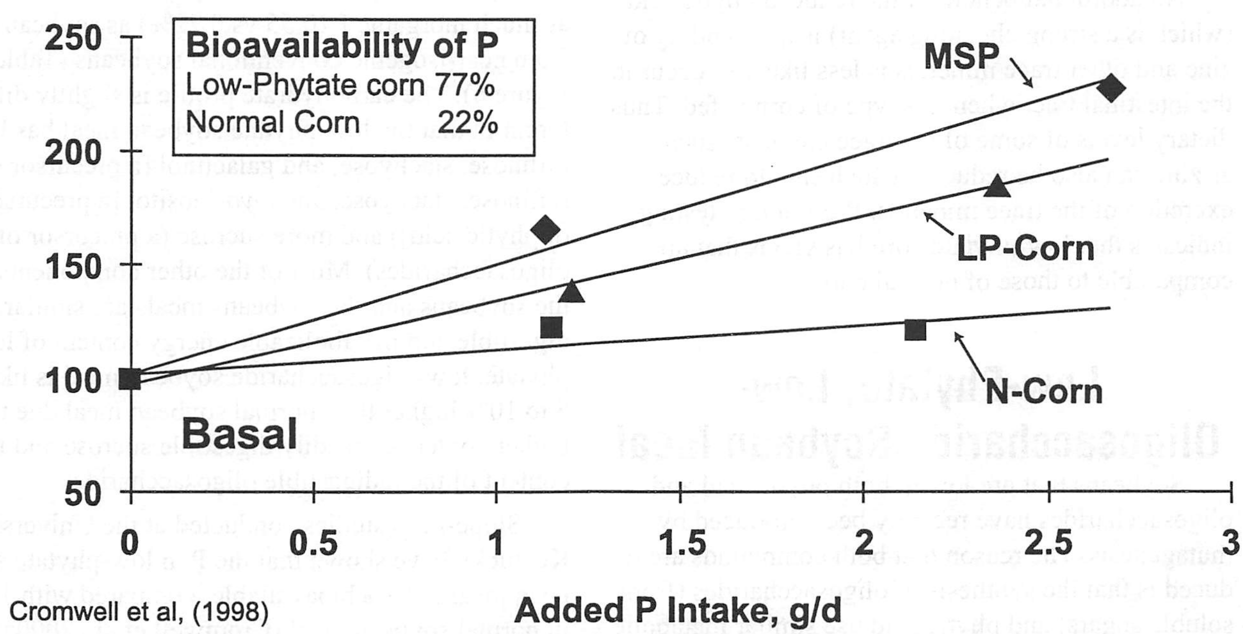


Figure 4. Relative Bone Traits of Pigs fed Monosodium Phosphate (MSP) and Normal or Low-Phytate Corn



Cromwell et al, (1998)

Table 4. Performance of growing pigs fed corn-soy diets with normal or low-phytate corn and varying amounts of supplemental inorganic phosphorus[a]

	Normal Corn				Low-Phytate Corn			
Total P, %:[b]	0.59	0.50	0.42	0.33	0.59	0.50	0.42	0.33
Bioavailable P, %:[c]	0.35	0.26	0.18	0.09	0.45	0.37	0.28	0.20
Daily gain, lb[d]	1.78	1.76	1.62	1.36	1.75	1.71	1.73	1.70
Feed/gain[d]	2.37	2.37	2.44	2.79	2.39	2.54	2.38	2.35
Bone traits								
Femur strength, kg[d]	308	301	234	125	332	332	298	208
MM strength, kg[d,e]	90	86	66	41	87	89	85	64
Relative strength[d,f]	100	97	75	43	102	103	96	69
MM ash, %[d]	50.6	50.6	48.7	45.2	51.0	50.9	50.4	46.9

[a]Pierce et al. (1998b). University of Kentucky experiment involving five replications of two pigs/pen from 51 to 112 lb body weight. Dietary lysine was 0.80% and dietary calcium was 0.65%.
[b]The diets with 0.33% total P had no supplemental P.
[c]Based on the following bioavailabilities of P: normal corn, 20%; low-phytate corn, 75%; soybean meal 25%; dicalcium phosphate, 100%.
[d]Effect of dietary P ($P < 0.01$); dietary P x corn type interaction ($P < 0.05$).
[e]MM = average of third and fourth metacarpal and metatarsal bones.
[f]Relative to the normal corn diet with the highest level of P. Mean of femur and MM.

tions in P excretion with the feeding of low-phytate corn.

An additional benefit of the reduced phytic acid (which is a strong chelating agent) is that binding of zinc and other trace minerals is less likely to occur in the intestinal tract when this type of corn is fed. Thus, dietary levels of some of the trace elements such as zinc can also be reduced, which should reduce excretion of the trace minerals. Preliminary testing indicates that low-phytate corn has yields that are comparable to those of normal corn.

Low-Phytate, Low-Oligosaccharide Soybean Meal

Soybeans that are low in both phytic acid and oligosaccharides have recently been produced by mutagenesis. The reason that both compounds are reduced is that the synthesis of oligosaccharides (from soluble sugars) and phytic acid use similar metabolic pathways. The down-regulation of key enzymes in the synthesis pathways of the mutant soybeans affects the amounts of both compounds (Figure 5).

Soybean meal produced from low-phytate, low-oligosaccharide soybeans has approximately half as much phytate P (0.22 vs 0.48%) and more than twice as much inorganic P (0.55 vs 0.22%) as soybean meal from near-isogenic conventional soybeans (Table 7, Figure 6). The carbohydrate profile is slightly different in that the low-phytate soybean meal has less raffinose, stachyose, and galactinol (a precursor of raffinose, stachyose, and *myo*-inositol [a precursor of phytic acid]) and more sucrose (a precursor of the oligosaccharides). Most of the other components in the soybeans and the soybeans meals are similar. The digestible and metabolizable energy content of low-phytate, low-oligosaccharide soybean meal is likely 5 to 10% higher than normal soybean meal due to the higher content of readily digestible sucrose and lower content of the indigestible oligosaccharides.

Slope-ratio studies conducted at the University of Kentucky have shown that the P in low-phytate soybean meal is 49% bioavailable, compared with 19% in normal soybean meal (Cromwell et al., 2000a; Figure 7). Spencer and co-workers (2000b) at the University of Missouri reported similar estimates of P bioavailability in the two soybean meals.

Table 5. Performance of finishing pigs fed corn-soy diets with normal or low-phytate corn and varying amounts of supplemental inorganic phosphorus[a]

Total P, %	Normal Corn			Low-Phytate Corn		
Phase 1:[b]	0.45	0.39	0.33	0.45	0.39	0.33
Phase 2:[b,c]	0.42	0.36	0.30	0.42	0.36	0.30
Bioavailable P, %:[d]	0.24	0.17	0.10	0.34	0.27	0.20
Phase 1						
Daily gain, lb[e]	2.13	2.12	2.00	2.17	2.15	2.16
Feed/gain[f]	3.23	3.10	3.31	3.12	3.11	3.07
Entire experiment						
Daily gain, lb	2.15	2.15	2.10	2.13	2.15	2.17
Feed/gain	3.44	3.38	3.48	3.39	3.39	3.35
Bone traits						
MM strength, kg[f,g]	181	177	156	181	185	187
Relative strength[f,h]	100	98	86	100	102	103
MM ash, %[f]	53.2	52.9	52.2	53.7	53.5	53.4
Carcass lean, %	53.7	53.9	53.1	54.0	54.0	53.7

[a]Pierce et al. (1998a). University of Kentucky experiment involving six replications of five pigs/pen from 115 to 240 lb body weight.
[b]Phase 1 was from 115 to 170 lb and Phase 2 was from 170 to 240 lb body weight. Dietary lysine was 0.85 and 0.65%, and dietary calcium was 0.54 and 0.52%, respectively.
[c]The diets with 0.30% total P had no supplemental P.
[d]Based on the following bioavailabilities of P: normal corn, 20%; low-phytate corn, 75%; soybean meal, 25%; dicalcium phosphate, 100%.
[e]Effect of dietary P in normal corn diets ($P < 0.05$).
[f]Effect of dietary P in normal corn diets ($P < 0.01$).
[g]MM = average of third and fourth metacarpal and metatarsal bones.
[h]Relative to the normal corn diet with the highest level of P.

In other studies, pigs fed diets consisting of low-phytate corn and low-phytate soybean meal with no supplemental inorganic P grew as fast and efficiently, had similar bone traits, and excreted 53% less P (Figure 8) than pigs fed diets containing conventional corn and soybean meal supplemented with sufficient inorganic P to meet the pig's P requirement (Cromwell et al., 2000b; Table 8). Similar findings also were reported by Spencer et al. (2000a,b).

The inclusion of supplemental phytase in diets containing low-phytate corn and soybean meal offers additional opportunity for reducing P excretion. Although it seems that the impact of phytase should be less in low-phytate feeds (because there is less substrate), there is evidence that P excretion is reduced when phytase is added to diets containing low-phytate corn and normal soybean meal is fed to young pig (Pierce and Cromwell, 1999; Table 9). Studies are currently underway to assess the effects of phytase addition to diets containing low-phytate corn and low-phytate soybean meal in diets for pigs.

Endogenous and Bioengineered Phytase in Plants

Some crops possess relatively high levels of endogenous phytase in their seeds. For example, early investigations by McCance and Widdowson (1944) and Mollgaard (1946) demonstrated that wheat, wheat byproducts (bran, middlings), rye, and to a lesser extent, barley, contain significant amounts

Table 6. Phosphorus balance of finishing pigs fed corn-soy diets with normal or low-phytate corn[a]

	Normal Corn	Low-Phytate Corn
Total P, %:[b]	0.42	0.30
Bioavailable P, %:[c]	0.20	0.20
P intake, g/day[d]	11.89	8.66
P retained, g/d	5.31	4.92
P excreted, g/day		
Feces[d]	5.85	3.64
Urine[d]	0.73	0.10
Total[d]	6.58	3.74
Reduction in P excretion, %[e]		43

[a]Pierce (1999). University of Kentucky 5-day balance experiment involving five pigs/treatment at approximately 220 lb body weight. Diets contained 0.65% lysine.
[b]Normal corn-soy diet contained 0.12% added P from dicalcium phosphate. Low-phytate corn-soy diet had no additional inorganic P.
[c]Based on the following bioavailabilities of P: normal corn, 20%; low-phytate corn, 75%; soybean meal, 25%; dicalcium phosphate, 100%.
[d]Normal vs low-phytate corn ($P < 0.01$).
[e]Reduction in P excretion compared with pigs fed the normal corn-soy diet.

Figure 5. Soluble Carbohydrates in Soybean

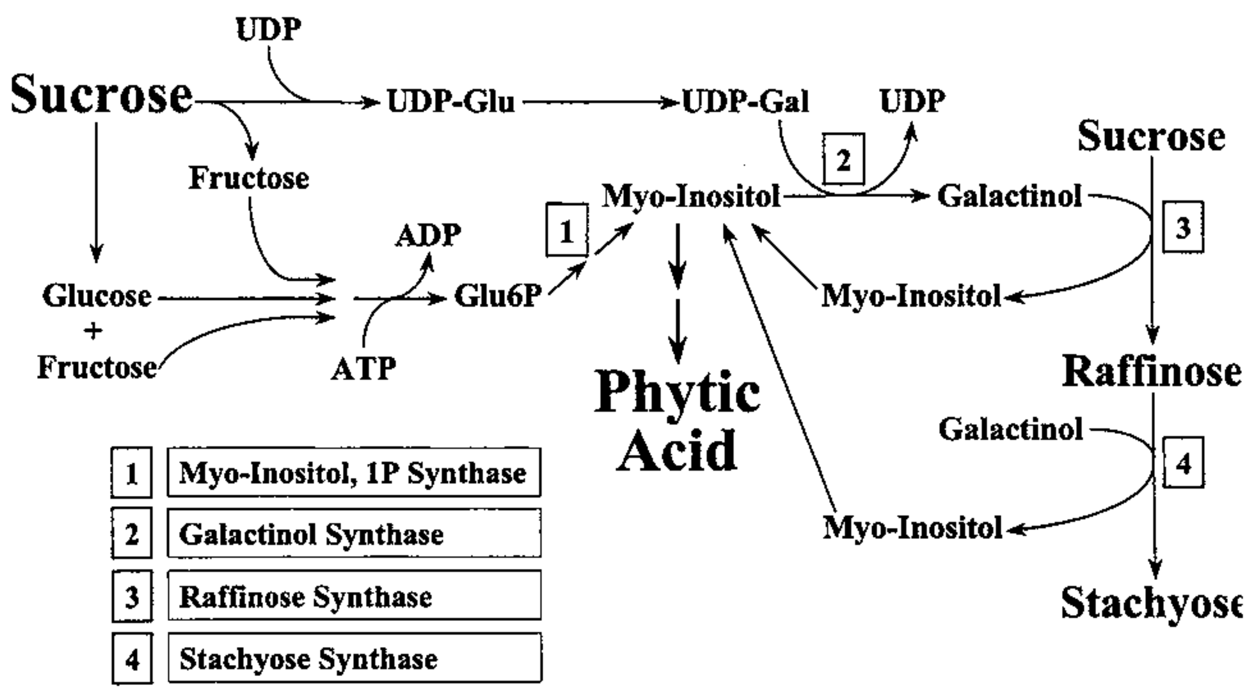


Table 7. Composition of normal and low-phytate, low oligosaccharide soybean meal[a]

Item	Normal Soybean Meal	Low-Phytate Soybean Meal
	%	%
Dry matter	95.8	95.8
Crude protein	53.6	55.3
Crude fat	0.94	0.57
Crude fiber	4.52	2.34
Calcium	0.35	0.36
Total phosphorus	0.70	0.77
Phytate phosphorus	0.48	0.22
Inorganic phosphorus	0.22	0.55
Amino acids		
Lysine	3.03	3.18
Threonine	1.97	2.01
Tryptophan	0.72	0.76
Methionine	0.80	0.83
Cystine	0.79	0.80
Isoleucine	2.42	2.52
Valine	2.56	2.68
Carbohydrates		
Sucrose	7.22	12.32
Galactinol	0.17	0.00
Raffinose	0.91	0.55
Stachyose	5.20	0.53

[a]DuPont Speciality Grains, Des Moines, IA. The normal and low-phytate soybeans from which the two soybean meals were prepared were near-isogenic.

of phytase. In studies at the University of Kentucky, we have found a considerably higher bioavailability of P in wheat (50%), wheat middlings (41%), wheat bran (29%), and barley (30%) than that in corn (14%) (Cromwell, 1993). Wheat phytase has also been shown to increase the utilization of P in other feedstuffs in the diet.

Biotechnology has now been used to insert a phytase gene into alfalfa (Anon, 1998; Ullah et al., 2002) and canola (McHughen, 2000), which greatly increases their phytase content. Commercialization of such crops should have considerable potential to reduce P excretion.

Transgenic Pigs Possessing Salivary Phytase

Scientists at the University of Guelph (Golovan et al., 2001; Forsberg et al., 2002) have recently produced several lines of transgenic pigs that have high levels of phytase in their saliva. Originally, the transgene that was introduced into pigs by pronuclear microinjection was composed of the mouse parotid secretory protein promoter and the *Escherichia coli appA* phytase gene (Golovan et al., 2000). In their transgenic pigs, high phytase activities were detected in the parotid, sublingual, and submaxillary salivary glands, resulting in substantial phytase activity in the contents of the stomach, duodenum, and ileum.

Figure 6. Forms of Phosphorus in Normal and Low-Phytate Soybean Meal

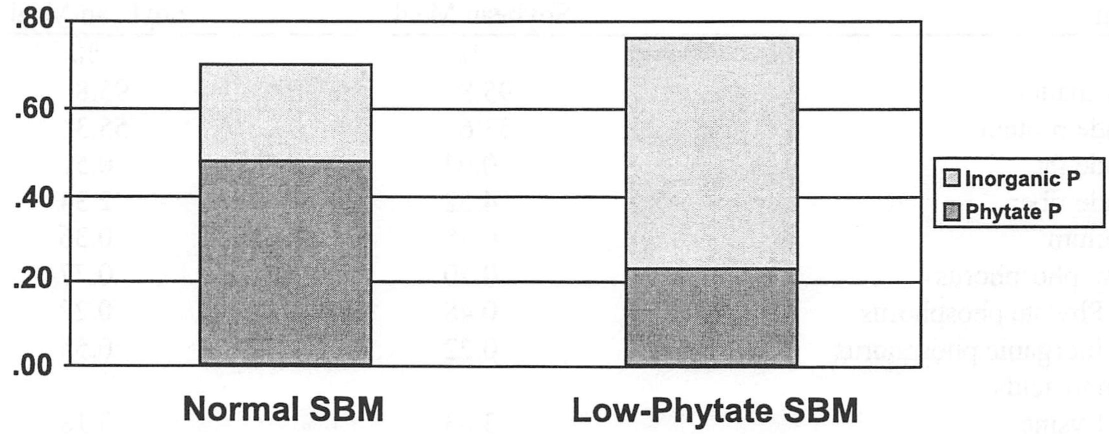
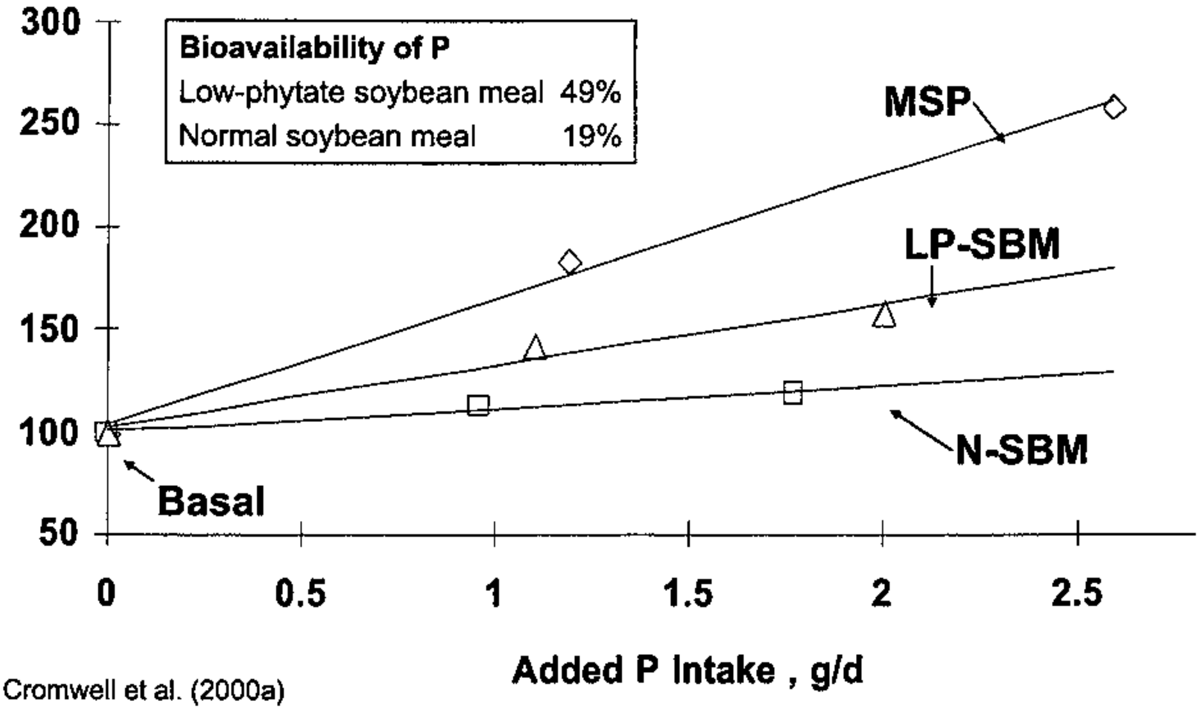


Table 8. Performance of growing pigs fed corn-soy diets with normal or low-phytate corn and normal or low-phytate soybean meal with varying amounts of supplemental inorganic phosphorus[a]

	Normal Corn + Normal Soybean Meal			Low-Phytate Corn + Low-Phytate Soybean Meal		
Supplemental P, %:	0.20	0.10	0.00	0.20	0.10	0.00
Total P, %:	0.56	0.46	0.36	0.59	0.49	0.39
Bioavailable P, %:[b]	0.27	0.17	0.07	0.44	0.34	0.24
Daily gain, lb[c]	1.76	1.66	1.38	1.77	1.76	1.74
Feed/gain[c]	2.22	2.30	2.62	2.24	2.16	2.19
Bone traits						
Femur strength, kg[c]	292	219	157	313	305	292
MM strength, kg[c,d]	83	61	42	74	84	80
Relative strength[c,e]	100	74	52	98	102	98
MM Ash, %[c]	56.5	54.2	51.7	56.5	56.9	56.2
Fecal P excretion, g/d[f]	7.0	6.2	5.3	5.1	4.0	3.3
Reduction in fecal P excretion, %[g]				27	43	53

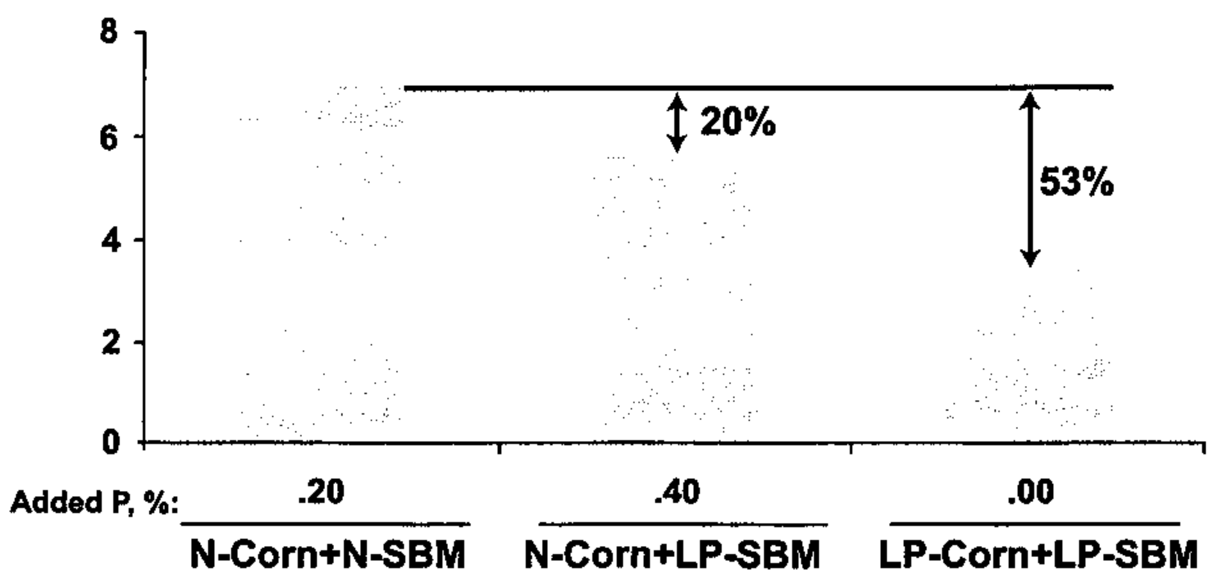
[a]Cromwell et al. (2000b). University of Kentucky experiment involving eight pens of individually fed pigs from 49 to 108 lb body weight. Dietary lysine was 0.95% and dietary calcium was 0.65%.
[b]Based on the following bioavailabilities of P: normal corn, 20%; low-phytate corn, 75%; normal soybean meal, 20%; low-phytate soybean meal, 50%; dicalcium phosphate, 100%.
[c]Linear effect of added P in normal corn-normal soybean meal diets ($P < 0.01$).
[d]Average of third and fourth metacarpal and metatarsal bones.
[e]Relative to the normal corn diet with the highest level of P. Mean of femur and MM.
[f]Linear effect of added P in both diets ($P < 0.01$).
[g]Reduction in P excretion compared with pigs fed the normal corn-normal soy diet with 0.56% total P.

Figure 7. Relative Bone Traits of Pigs Fed Monosodium Phosphate (MSP) and Normal or Low-Phytate Soybean Meal



Cromwell et al. (2000a)

Figure 8. Fecal P Excretion in Pigs Fed Normal and Low-Phytate Corn and Soybean Meal



Cromwell et al, (2000b)

Table 9. Bone traits and phosphorus excretion by pigs fed corn-soy diets with normal or low-phytate corn and supplemented with microbial phytase[a]

Corn type:	Normal	Normal + Phytase[b]	Low-Phytate	Low-Phytate + Phytase[b]
Total P, %:[c]	0.55	0.45	0.45	0.35
Bioavailable P, %:[d]	0.29	0.19	0.29	0.19
Femur strength, kg	272	265	282	283
MM strength, kg	73	66	73	73
Relative strength[e]	100	94	102	102
MM ash, %	52.8	53.0	52.3	53.6
Fecal P excretion, g/d[f]	6.80	5.24	4.43	3.34
Reduction in fecal P excretion, %[g]		23	35	51

[a]University of Kentucky experiment involving six pens of two pigs each per treatment from approximately 41 to 105 lb body weight. Dietary lysine was 0.95% and calcium was 0.60%.
[b]Natuphos® supplied 600 phytase units/kg of diet.
[c]The 0.35% P diet contained no additional inorganic P.
[d]Based on the following bioavailabilities of P: normal corn, 20%; low-phytate corn, 75%; soybean meal, 25%; dicalcium phosphate, 100%.
[e]Relative to the normal corn diet with the highest level of P. Mean of femur and MM.
[f]Normal vs low-phytate corn ($P < 0.05$). Effect of phytase ($P < 0.05$).
[g]Reduction in P excretion compared with pigs fed the normal corn-soy diet.

Table 10. Ability of transgenic pigs containing high salivary phytase to utilize phytate phosphorus[a]

	Control Pigs	Transgenic Pigs
Median salivary phytase, units/ml	0	2,420[b]
True digestibility of soybean meal P, %		
Weanling pigs	48.5	87.9
Growing-finishing pigs	51.9	98.8
Fecal P, % of dry matter		
Weanling pigs	3.4	0.8
Growing-finishing pigs	3.0	1.3

[a]Adapted from Golovan et al. (2001), University of Guelph.
[b]Saliva from transgenic pigs ranged from 341 to 10,077 phytase units/ml.

The presence of salivary phytase in transgenic pigs appears to have a greater effect than when supplemental phytase is added to conventional feeds or when low-phytate corn and soybean meal are fed. In the Guelph studies, the true digestibility of soybean meal P by the transgenic pigs was very high, 88 to 99%, and excretion of P was reduced by as much as 75% in weanling pigs (Table 10). They attributed this dramatic response to the much larger amount of enzyme continuously present in the stomach of the transgenic pig due to the copious secretion of saliva when feed is consumed (Corring, 1980). Consequently, these pigs may have delivered as much as 200,000 units of phytase to the digestive tract during the consumption of 1 kg of feed. This is considerably more than the normal phytase supplementation of 300 to 1,000 units of phytase per kg of feed.

Whether this new finding will become practical remains to be seen, but it certainly opens up a new biological approach for reducing phosphorus pollution in animal agriculture.

Implications

A number of technologies are available or will soon become available that will help to reduce the P concentration in swine manure. An appropriate reduction in the dietary P level along with the addition of one of the available phytase supplements is the most effective means at the present time. As more low-phytate corn becomes commercially available, this will also provide a means of reducing P excretion by swine. The eventual commercialization of low-phytate soybean meal will be an additional bonus. Transgenic pigs having high levels of phytase in their saliva may someday be accepted in practice. These and other new technologies provide exciting times for the future of animal agriculture.

References cited

Anon. 1998. Transgenic alfalfa yields new products. Agric. Res. April, 1998, p. 25.

Carter, S. D., G. L. Cromwell, M. D. Lindemann, L. W. Turner, and T. C. Bridges. 1996. Reducing N and P excretion by dietary manipulation in growing and finishing pigs. J. Anim. Sci. 74(Suppl. 1):59 (abstr.).

CAST. 2002. Animal Diet Modification to Decrease the Potential for Nitrogen and Phosphorus Pollution. Issue Paper 21. Council for Agricultural Science and Technology, Ames, IA.

Corring. T. 1980. Endogenous secretions in the pig. In: A. G. Low and I. G. Partridge (eds.) Current Concepts of Digestion and Absorption in Pigs. pp. 136-150 . National Institute for Research in Dairying, Reading.

Cromwell, G. L. 1993. An assessment of the bioavailability of phosphorus in feed ingredients for nonruminants. In: Proc. Maryland Nutrition Conf., Baltimore,MD. pp. 146-158. Univ. Maryland, College Park, MD.

Cromwell, G. L. 1996. Low protein, amino acid supplemented diets for growing-finishing pigs. Proc. 16th Prince Agri Feed Ingredient Conference. Quincy, IL, pp. 13-26.

Cromwell, G.L., R.D. Coffey, G.R. Parker, H.J. Monegue, and J.H. Randolph. 1995. Efficacy of a recombinant-derived phytase in improving the bioavailability of phosphorus in corn-soybean meal diets for pigs. J. Anim. Sci. 73:2000-2008.

Cromwell, G. L., J. L. Pierce, T. E. Sauber, D. W. Rice, D. S. Ertl, and V. Raboy. 1998. Bioavailability of phosphorus in low-phytic acid corn for growing pigs. J. Anim. Sci. 76(Suppl. 2):54 (abstr.).

Cromwell, G. L., S. L. Traylor, M. D. Lindemann, T. E. Sauber, and D. W. Rice. 2000a. Bioavailability of phosphorus in low-oligosaccharide, low-phytate soybean meal for pigs. J. Anim. Sci. 78(Suppl. 2):71 (abstr.).

Cromwell, G. L., S. L. Traylor, L. A. White, E. G. Xavier, M. D. Lindemann, T. E. Sauber, and D. W. Rice. 2000b. Effects of low-phytate corn and low-oligosaccharide, low-phytate soybean meal in diets on performance, bone traits, and phosphorus excretion by growing pigs. J. Anim. Sci. 78(Suppl. 2):72 (abstr.).

Forsberg, C.W., J.P. Phillips, S.P. Golovan, R. G. Meidinger, M. Cottrill, A. Ajakaiye, M.Z. Fan, D. Hilborn, and R.R. Hacker. 2002. The Enviropig™ physiology, performance and potential contribution to nutrient management. J. Anim. Sci. 80(Suppl. 1): 54 (abstr.).

Golovan, S. P., R. G. Meidinger, A. Ajakaiye, M. Cottrill, M.Z. Wiederkehr, D. J. Barney, C. Plante, J. W. Pollard, M. Z. Fan, M. A. Hayes, J. Laursen, J. P. Hjorth, R. R. Hacker, J. P. Phillips, and C. W. Forsberg. 2001. Pigs expressing salivary phytase produce low-phosphorus manure. Nature Biotechnol. 19:731-745.

Golovan, S. P., G. Wang, J. P. Hjorth, and C. W. Forsberg. 2000. Characterization and overproduction of the *Escherichia coli appA* encoded bifunctional enzyme which exhibits both phytase and acid phosphatase activities. Can. J. Microbiol. 46:59-71.

McCance, R. A., and E. M. Widdowson. 1944. Activity of the phytase in different cereals and its resistance to dry heat. Nature 153:650.

McHughen, A. 2000. Biotechnology and Feed, 2nd ed. p.16. American Council on Science and Health, New York, NY.

Mollgaard, H. 1946. On phytic acid, its importance in metabolism and its enzymic cleavage in bread supplemented with calcium. Biochem. J. 40: 589.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. National Academy Press, Washington, DC.

Nelson, T. S., L. W. Ferrara, and N. L. Storer. 1968. Phytate phosphorus content of feed ingredients derived from plants. Poul. Sci. 47:1372-1374.

Pierce, J. L. 1999. Nutritional assessment of conventional and low phytic acid corn for pigs and chicks. PhD Dissertation, University of Kentucky, Lexington.

Pierce, J. L. and G. L. Cromwell. 1999. Phytase addition to normal corn- and low-phytic acid corn-soybean meal diets for chicks and pigs. J. Anim. Sci. 77(Suppl. 1):175 (abstr.).

Pierce, J. L., G. L. Cromwell, and V. Raboy. 1998a. Nutritional value of low-phytic acid corn for finishing pigs. J. Anim. Sci. 76(Suppl. 1):177.

Pierce, J. L., G. L. Cromwell, T. E. Sauber, D. W. Rice, D. S. Ertl, and V. Raboy. 1998b. Phosphorus digestibility and nutritional value of low-phytic acid corn for growing pigs. J. Anim. Sci. 76(Suppl. 2):54.

Raboy, V., D. B. Dickinson, and M. G. Neuffer. 1990. A survey of maize kernel mutants for variation in phytic acid. Maydica 35:385-390.

Sands, J. S., D. Ragland, C. Baxter, B. C. Joern, T. E. Sauber, and O. Adeola. 2001. Phosphorus bioavailability, growth performance, and nutrient balance in pigs fed high available phosphorus corn and phytase. J. Anim. Sci. 79:2134-2142.

Spencer, J. D., G. L. Allee, J. W. Frank, and T. E. Sauber. 2000a. Nutrient retention and growth performance of pigs fed diets formulated with low-phytate/low-oligosaccharide soybean meal. J. Anim. Sci. 78(Suppl. 2):73 (abstr.).

Spencer, J. D., G. L. Allee, J. W. Frank, and T. E. Sauber. 2000b. Relative phosphorus availability and retention of low-phytate/low-oligosaccharide soybean meals for growing pigs and chicks. J. Anim. Sci. 78(Suppl. 2):73 (abstr.).

Spencer, J. D., G. L. Allee, and T. E. Sauber. 2000c. Phosphorus bioavailability and digestibility of normal and genetically modified low-phytate corn for pigs. J. Anim. Sci. 78:675-681.

Sweeten, J. M. 1992. Livestock and poultry waste management: A national overview. In: J. Blake, J. Donald, and W. Magette (Eds.) National Livestock, Poultry and Aquaculture Waste Management. pp. 4-15. ASAE, St. Joseph, MI.

Turner, L.W., G. L. Cromwell, T. C. Bridges, S. Carter, and R. S. Gates. 1996. Ammonia (NH_3) emission from swine waste as influenced by diet manipulation. Proceedings of 1st International Conference on Air Pollution from Agricultural Operations. Kansas City, MO. Feb. 5-9, 1996. MidWest Plan Service, Iowa State Univ., Ames, pp. 453-458.

Ullah, A.H., K. Sethumadhavan, E.J. Mullaney, T. Ziegelhoffer, and S. Austin-Phillips. 2002. cloaned and expressed fungal *phyA* genes in alfalfa produces a stable phytase. Biochem. Biophy. Res. Comm. 290: 1343-1348.

Veum, T. L., d. R. Ledoux, V. Raboy, and D. S. Ertl. 2001. Low-phytic acid corn improves nutrient utilization for growing pigs. J. Anim. Sci. 79:2873-2880.

Effect Of Feeding Strategies On Nutrient Excretion With Manure and Performance of Grower-Finishing Pigs

C.F.M. de Lange, Associate Professor, Department of Animal and Poultry Science
University of Guelph, Guelph, Ontario, CANADA , N1G 2W1

Summary

In many areas of the world the contribution of animal agriculture to environmental pollution has become a serious concern. Via alternative management practices, the mineral balance on animal farms can be substantially improved. Via the use of phytase, synthetic amino acids and by feeding more closely to the animals requirements, the phosphorus and nitrogen excretion with pig manure can be reduced by up to 50%. Factorial approaches to estimate phosphorus and amino acid requirements for individual groups of pigs are suggested and compared to Nutrient Requirements of Swine (NRC, 1998). Application of nutritional strategies to reduce mineral excretion will increase the need for accurate evaluation of available nutrient content in pig feed ingredients, precise feed formulation and manufacturing, and accurate estimation of body protein and phosphorus retention in individual groups of growing pigs.

Introduction

In areas with intensive pig production, the negative impact of pig production on the environment is one of the main factors that limits the expansion of the pork industry and affects the attitude of the general public towards animal production (e.g. Kornegay and Verstegen, 2001). This negative impact is the result of releasing odorous compounds and compounds that contribute to acid rain from swine facilities, as well as the disposal of nutrients and potentially harmful micro-organisms with swine manure. In several countries legislation has been introduced, or recommendations have been made, to reduce or to minimize the contribution of animal agriculture to environmental pollution. These imposed regulations, or recommendations, generally increase production costs and have forced the agricultural industry to seek means to reduce the production of animal waste.

In this paper some nutritional means to reduce the excretion of nutrients in pig manure will be described briefly. Nutrients that are of prime concern in regards to nutrient management are copper (Cu), zinc (Zn), nitrogen (N), and phosphorus (P). Potassium (K) should be considered as well, as it affects the fertilizing value of manure. Some areas, where further information is required are identified as well.

Copper and Zinc

In general, Cu and Zn in pig diets are much higher than the minimum requirements for normal performance (i.e.: 5-25 Cu and 50-125 ppm Zn for the various classes of swine; NRC 1998). These minerals act as growth promotants when included at levels much higher than minimum requirements. In Canada, the federal Feeds Act limits the maximum level of Cu and Zn in the diet to 125 ppm and 500 ppm respectively. Apparently in the US, much higher levels are common. In some countries, like the Netherlands, growth-promoting levels of Cu and Zn are no longer allowed in finisher pig diets due to the impact on the environment. As long as minimum requirement levels of Cu and Zn are maintained, the excretion of these minerals in pig manure is not a concern; the focus then switches to P and N excretion.

Mineral balances

The whole farm or animal efficiencies with which minerals are retained in useable animal products are generally low. On swine farms, the efficiency of mineral retention is very low for potassium (3.6 to 10%) and somewhat higher for nitrogen and phosphorus (18 to 40%) (Table 1). The efficiency of

Table 1. Typical mineral balances (kg/animal) on Dutch pig farms (Jongbloed, 1991).

	Nitrogen	Phosphorus	Potassium
	I. growing pigs (25-106 kg live weight)		
Dietary levels (%)	16.7*	.52	1.22
Intake (kg/pig)	6.36	1.23	2.90
Excretion (kg/pig)	4.48	.83	2.73
Retention (kg/pig)	1.88	.40	.17
Recovery (%)	29.5	32.5	6.0
	II. Sows, including nursing piglets		
Dietary levels (%)	15.7*	.59	1.32
Intake (kg/sow/yr)	27.57	6.53	14.52
Excretion (kg/sow/yr)	22.50	5.5	14.0
Retention (kg/sow/yr)	5.07	1.03	.52
Recovery (%)	18.4	15.8	3.6
	III. Starter pigs (9-25 kg live weight)		
Dietary levels (%)	18.4*	.67	1.25
Intake (kg/pig)	.94	.21	.40
Excretion (kg/pig)	.56	.13	.36
Retention (kg/pig)	.38	.08	.04
Recovery (%)	40.5	39.4	10.0

*Total protein (Nx6.25) rather than N.

mineral retention on swine farms is generally lowest in sows and highest in starter pigs. On a typical farrow to finish operation, growing-finishing pigs produce 70% of the manure. For this reason 'average' farm values will be close to those for growing-finishing pigs.

These low efficiencies of mineral retention indicate that there is room for improvement, and that the excretion of minerals with manure can be reduced. There is considerable variation in the efficiency of N, and P retention between different pig farms. This can be attributed to various feed and animal factors, including:

- feed wastage,
- the availability of N (amino acids; AA) and P in the various feedstuffs or diets,
- animal performance levels, and
- discrepancies between requirements and dietary levels of available AA and P.

Given this large variation and environmental pressures, the need to closely monitor N and P balances on individual pig units will increase. This can be best accomplished by closely monitoring the amount and composition of feeds (*or feed ingredients*) that are used and the number and weight of animals (*live and dead*) that are removed from the farm. In the Netherlands, such a mineral book keeping system is obligatory for farms that have more than 2.5 large animal units (*about 10 growing-finishing pig places*) per hectare of land, and requires that feed companies provide statements regarding amounts of nutrients that are delivered to each farm. With this approach, the calculated nutrient balances are rather sensitive to initial and final nutrient inventories with feed and manure (MINAS, 2002). In Ontario, Canada, this approach to calculating nutrient balances has been integrated in a computer program used to develop nutrient management plans for individual animal production units (Goss et al., 1997; Birkett and de Lange, 1998).

Nutritional means to reduce mineral excretion in farm animals

Over the last few years some extensive reviews have been published in which various nutritional means to improve the efficiencies of N and P retention in pigs are addressed (e.g. Verstegen et al., 1993; Lenis and Jongbloed, 1995; Coelho and Kornegay, 1996; NRC 1998; Kornegay and Verstegen, 2001). In this paper, only the main and most relevant means to improve the efficiency of N and P retention will be discussed. Other means, including plant breeding (*to manipulate feed ingredients from plant origin*), feed ingredient selection, use of enzymes other than phytases, and feed processing are discussed elsewhere (e.g. Verstegen et al., 1993; Lenis and Jongbloed, 1995; Coelho and Kornegay, 1996; NRC 1998; Kornegay and Verstegen, 2001).

Means to reduced phosphorus excretion with pig manure

Assessing and improving phosphorus availabilities in pig diets

The major reason for the inefficiency of P utilization in monogastric animals is the poor digestibility/availability of P that is present in plant products (Table 2), largely because much of P in plant products is present in the phytate form. In contrast, the availability of P in animal and inorganic sources (*meat and bone meal, di- and mono-calcium phosphate*) is much higher (65 *to 90%*). For this very simple reason, pig diets should be formulated on an available/digestible basis, rather than a total P basis.

Some plant products, in particular wheat products, contain some natural enzymes (*phytases*) that can liberate P from phytates and contribute to improvements in P availability in these ingredients.

For determining the availability of phosphorus in ingredients for swine, two different approaches have been used. The approach that is used in the United States is based on a slope-ratio assay in which bone characteristics are related to the inclusion level of the test source of phosphorus in the diet (Cromwell, 1993; NRC, 1998). Values are compared to a standard source of phosphorus, monosodium phosphate. The second approach, used in The Netherlands and France, is to determine apparent faecal phosphorus digestibility in phosphorus sources at low levels of phosphorus intake (e.g. Jongbloed, 1987; CVB, 1998; Jongbloed et al., 1999). A comparison of estimated availabilities of phosphorus in the various ingredients using the two techniques is provided in Table 2. The CVB (1998) digestibility values are divided by .87, the digestibility of monosodium phosphate, to allow for a direct comparison to the NRC (1998) availability values. The data shows some general agreement for most feed ingredients. However, differences can be noted for some ingredients, such as canola meal,

Table 2. Phosphorus availability (%) according to NRC (1998) and CVB (1990; 1998) in various pig feed ingredients.

Ingredient	NRC	CVB*
Corn	14	23
Barley	30	34(45)**
Wheat	50	30(55)
SBM, hulled	31	45
SBM, dehulled	23	45
Canola meal	21	31
Meat and bone meal	90 (can be as low as 70)	93
Peas	-	52
Dicalcium Phosphate $2H_20$	95-100	80
Monocalcium Phosphate – base*	100	100

* CVB values are divided by .87 for comparison with NRC values.

** Values in between brackets include endogenous phytase activity.

dehulled SBM and dicalcium phosphate. In The Netherlands, the above has lead to an increase in the use of monocalcium-phosphate, rather than dicalcium-phosphate, as the mineral source of choice in pig diets.

Differences between NRC (1998) and CVB (1998) values may be attributed to within ingredient variability, but more likely to methodologies that are used to assess availability or digestibility. Main concerns with the slope-ratio assay are the expense and invasiveness of the technique (multiple diets are needed to evaluate one ingredient and animals need to be sacrificed), effects of diet nutrient balance on observed P availability (in particular the diet calcium to P ratio), and lack of precision/repeatability. In contrast, apparent faecal P digestibility can be determined relatively easily, while comparisons between P sources can be made within animals (Yi and Kornegay, 1996; Jongbloed et al., 1999). In a direct comparison of the two techniques, the digestibility assay yielded more repeatable results than the bone-breaking strength assay (Jongbloed, 1987; Yi and Kornegay, 1996). Concerns with the faecal digestibility assay are the potential impact of endogenous gut P losses on observed apparent faecal digestibility and the fact that regulation of P absorption is an important aspect of P homeostasis. In pigs, urinary P excretion is minimal, at about 1% of phosphorus intake, while the rate of P absorption from the intestinal lumen is down regulated at high levels of P intake (Jongbloed et al., 1999). Recent studies at the University of Guelph have shown that apparent faecal P digestibility is relatively constant over a considerable range of diet P levels, while apparent faecal P digestibility was reduced at very low diet P levels, which may be attributed to the relatively large contribution of (minimum) endogenous gut P losses to faecal P excretion at low levels of diet P (Fan et al., 2001). Based on these considerations, faecal P digestibility values should be preferred over P availability values when formulating swine diets. Apparent digestibility values may be corrected for (minimum) endogenous gut P losses to generate true, or standardized, faecal P digestibility values for swine feed ingredients (Fan et al., 2001; Fan and Sauer, 2002).

In ingredients of plant origin there is reasonable agreement between P availability/digestibility and the proportion of total P that is present in the phytate form (CVB, 199). Recent studies at the University of Guelph indicate considerable variability in Ontario grown samples of corn and whole soybeans (Table 3). For US soybeans, Raboy et al. (1984) reported phytate contents ranging between 1.39 and 2.30%, and the proportion of P present in phytate ranging between 67 and 78%. For 45 US corn samples, Cromwell et al. (1999) reported a mean P content of 0.30%, range 0.26 to 0.36%, while limited information is available about phytate content in US corn samples. This large variability within these two ingredients warrants some routine monitoring of total P and phytate content in swine feed ingredients. In the Canadian study, year effects on total P and phytate content were quite substantial, while growing location and variety were significant factors influencing total P and phytate content in soybeans and corn, respectively (Leech and de Lange, 2001, 2002).

Microbially produced phytases are now routinely included in pig and poultry diets to enhance P digestibility (Simmons et al., 1990; Jongbloed and Kemme, 1990; Cromwell et al., 1993; Kornegay and Verstegen, 2001)(Table 4). As a result the total P levels in the diet can be reduced, the efficiency with which phosphorus is retained in the animal is improved, and the excretion with P into the environment is reduced (e.g. Coelho and Kornegay, 1996).

Various points should be considered when including phytases in pig diets (Jongbloed and Kemme, 1990; Simons et al., 1990; Jongbloed et al., 1993; Coelho and Kornegay, 1996; Kornegay and Verstegen, 2001):

- Different commercial products differ in the content of active phytase. Phytase units (PTU) may be used to compare different products using a standardized test.
- The efficacy of phytases is not the same for all feed ingredients and diets (Table 4). This likely reflects differences in the location within the seed where phytate is deposited, e.g. in the germ in corn and the aleurone layer in wheat (O'Dell et al. 1972).
- Phytases are quite unstable when exposed to heat. During pelleting the temperature of the feed should not exceed 70-75 oC when phytases are included. Phytase activity should be checked in the complete, processed feed. In the near future phytases with higher heat stability will become available.
- Phytases not only increase the digestibility of P; they also increase the digestibility of calcium (Ca) and other trace minerals that are tied to the phytate complex (Cu, Zn, etc.). Phytase can improve feed utilization (by 1-2%) in starter and grower pigs

Table 3. Total phosphorus, phytate and the proportion of P present in phyate (%Phytate Phosphorus) in Ontario samples of corn and soybeans (Leech and de Lange, 2001, 2002).

		Corn	Soybeans
	Number of samples	222	108
Total Phosphorus, %	Mean ± SD	0.30 ± .03	0.58 ± .09
	Range	0.24 to 0.46	0.36-0.84
Phytate, %	Mean ± SD	0.76 ± .10	1.16 ± .25
	Range	0.51 to 1.04	0.55-1.89
% Phytate Phosphorus,%	Mean ± SD	71.3 ± 7.4	56.2 ± 5.1
	Range	48.6 to 89.4	43.3-70.7

Table 4. Effect of microbial phytase on phosphorus digestibility in growing pigs (Simons et al., 1990).

	Control	+ 1000 IU/kg phytase
	Corn – soybean meal diet	
Total Phosphorus (g/kg)	3.3	3.3
Phosphorus digest. (%)	20	46
	Practical Dutch grower diet*	
Total Phosphorus (g/kg)	4.1	4.1
Phosphorus digest. (%)	34	56

*Contains tapioca, hominy feed and soybean meal as the major ingredients.

by making other nutrients more available as well (e.g. Mroz et al., 1994). This results in additional "value" of added phytase.

- When determining the value of phytase, the effects of reducing the P and Ca levels in the diet should be considered. In particular, in high energy diets in which (expensive) fat is used, a reduction in mineral levels will be associated with a reduced need to use fat as there is more "space" in the feed formula. This results in reduction of ingredient costs.
- The marginal improvement in P digestibility declines with increasing added phytase level (Kornegay and Verstegen, 2001). The value of phytase is larger at low levels (less than 200 PTU/kg of feed: .021 % extra dig. P/ kg of feed per 100 additional PTU) than at intermediate levels (200 to 600 PTU/kg of feed: .010 % extra dig. P / kg of feed per 100 adiitonal PTU). At high levels, improvements in P digestibility are further reduced (more than 600 PTU/kg of feed: .0035 % extra dig. P/ kg of feed per 100 additional PTU). Furthermore, there is still some debate about the effect of pig age/weight on the response to phytase (it may be better than the indicated values at higher body weights).
- The utilization of P is affected by the calcium to P ratio in the diet; these should be maintained low (see next section).

In corn and soybean meal based diets, adding 500 PTU per ton in the diet can replace 0.1% of added P from dicalcium phosphate (Kornegay and Verstegen, 2001). This will reduce P excretion by about 25%, if diet P level is reduced from 0.6 to 0.5%. Given the above considerations and given today's prices of phytase and inorganic P sources, the use of phytase does not appear to increase feed cost by much. The cost of the product is largely offset by the reduced need for P and Ca in the feed.

Feed phosphorus more closely to the pigs' requirements

The actual P (and other nutrient) levels in diets are often higher than levels that are actually required by pigs. These "safety" margins are sometimes very large. Reasons for these safety margins (*and means to reduce these*) include:

- To account for potential errors in feed preparation and delivery (feed mixing equipment should be calibrated; ingredients and prepared diets should be sampled and analyzed).
- Only a few diets are used to meet the nutrient requirements of a wide range of pigs (apply phase and split-sex feeding; keep and manage breeding stock separate from market hogs).
- The Ca to P ratio in the diet is too high (keep it around 1.2) which reduces P utilization. According to Jongbloed et al. (1993, 1999) and Liu et al. (1998), dietary calcium levels should be related to digestible (or available) phosphorus levels rather than total phosphorus levels in the diet. These authors suggest that 2.9 is the optimum ratio between total calcium and digestible phosphorus, with an acceptable range from 2.7 to 3.2.
- The perceived requirements of some groups of pigs, with high performance potentials, are higher than the actual requirements (use common sense; follow published guidelines; develop a factorial or modeling approach to estimate the P requirements for different groups and genotypes of pigs; Table 5).

In the Netherlands, the available P allowances for the various classes of swine are 0.41% for starter pigs, 0.25% for grower pigs, 0.20% for finisher pigs, 0.25% for dry sows and .36% for nursing sows (CVB, 1990). In particular, the available P levels for the finisher pigs and dry sows are lower than those in practical diets in North America. A reduction in available P allowances will reduce the excretion of P with swine manure and reduce feed costs. A reduction in P intake by 10% will reduce P excretion with manure by approximately 15%.

The main determinant of available/digestible P requirements is P retention in the animal's body, while P losses with urine and the integument contribute little to P requirements (ARC, 1981; Hendriks and Moughan, 1993; Jongbloed et al., 1999). If

Table 5. Estimates of apparent faecal digestible P requirements in growing pigs according to a simple factorial approach and NRC (1998).

Scenario				Estimated requirements	
BW (kg)	BW gain[&] (g/d)	Protein gain (g/d)	Feed usage (kg/d)	Factorial* (% in diet)	NRC (1998)** (% in diet)
20	535	90	1.02[#]	0.28	0.24
20	644	120	1.02[#]	0.38	0.24
60	850	110	2.24[#]	0.16	0.17
60	1031	160	2.24[#]	0.23	0.17
60	964	160	2.02[@]	0.26	0.17
100	926	110	2.84[#]	0.13	0.13
100	1109	160	2.84[#]	0.18	0.13
100	1025	160	2.56[@]	0.20	0.13

[&] Estimated using NRC (1998).

* Daily apparent fecal digestible P requirements (g/d) were calculated from P retention (protein gain x 0.0302; Hendriks and Moughan, 1993; these are close to maximum P retention rates) plus urinary P losses (1 mg/kg empty BW/d; Jongbloed et al. 1999). Daily requirements were divided by feed intake to generate dietary requirements (%).

** Based on NRC (1998), but multiplied by 0.87 to make values comparable to estimates based on an apparent fecal digestible basis (Table 2). Actual NRC (1998) generated requirements are 0.28, 0.19 and 0.15%, for 20, 60 and 100 kg BW pigs, respectively.

[#] Equivalent to 90% of voluntary intake according to NRC (1998) and based on a diet DE content of 3400 Kcal/kg.

[@] Intake reduced by 10%.

diets are formulated on an apparent faecal digestible basis, then there is no need to consider endogenous gut P losses in P requirements. However, if diets are formulated based on a true or standardized digestible basis, then the total or minimum endogenous gut P losses should be considered as well (Jongbloed et al., 1999; Fan et al., 2001). These concepts are consistent with the use of (ileal) amino acid digestibility values in swine diet formulation (e.g. de Lange and Fuller, 2000). According to Jongbloed et al. (1999), P retention in the pig's body can best be estimated from live body weight. However, Hendriks and Moughan (1993) established that P retention is related more closely to lipid free tissue gain and body protein gain than to live body weight gain. The latter would also reflect the higher P requirements of pigs with high lean tissue growth rates, or gender effects on P requirements. For typical pigs the estimated rate of P retention is slightly higher based on Hendriks and Moughan (1993) than based on Jongbloed et al. (1999). For pigs with below average body protein gains and typical feeding levels, factorially estimated requirements for phosphorus are quite similar to NRC (1998)(Table 5). However, for pigs with high body protein gains and low feeding levels, it appears that NRC (1998) underestimates P requirements quite substantially. According to NRC (1998), pig genotype and feeding level doe not influence available P requirements. It is apparent that more information is obtained on P retention rates in modern pig genotypes and that this simple factorial approach to estimate P requirements of pigs needs some validation.

Means to reduced N excretion with pig manure

Improve the dietary amino acid balance

The balance in which amino acids are supplied in the diet differs substantially from the balance in which they are required for optimum performance by the various classes of swine. In typical corn and soybean meal based diets fed to grower pigs, about 25% of ingested protein is supplied by "unbalanced" amino acids. Unbalanced amino acids are degraded, are used as a source of energy, and contribute to N excretion with urine. About half of N excretion in pig manure can be attributed to the poor amino acid balance in the pigs' diet (Table 1). Various experiments have been conducted demonstrating that N excretion can be reduced, while pig growth performance is at least maintained by improving the diet amino acid balance and reducing total protein intake. For example, based on this approach, Tuitoek et al. (1997a,b) we were able to reduce N excretion in growing pigs fed corn-soybean meal diets by close to 40%.

A simple means to improve the dietary amino acid balance is to replace some of the standard protein sources (*e.g. soybean meal*) with purified synthetic amino acids (*lysine HCl, threonine, methionine, tryptophan*). In Table 6, potential reductions in N excretion are presented when diets are fed that differ in protein levels but that are balanced for amino acids. The estimated costs of these diets are given as well. If some of the soybean meal is replaced with lysine·HCl, both feed cost and the excretion of N with pig manure are reduced. There is a cost associated with further reductions in dietary protein levels. Given the costs of synthetic amino acids, it does not make economic sense to include synthetic amino acids, other than lysine·HCl, in grower pig diets. This will change when the availability and price of the other synthetic amino acids will improve. The use of synthetic amino acids also requires that diets be mixed properly and that requirements of the various essential amino acids and total N be estimated accurately. Based on the scenario presented in Tables 6 and 7, valine will become limiting before isoleucine and total N when replacing soybean meal protein with synthetic amino acids. It should be noted that the order in which amino acids become limiting will vary with pig BW, body protein gain and feeding level (see next section).

There are two additional benefits of reducing the total protein levels in pig diets: 1) excessive protein intake may induce scours, in particular in young pigs, and 2) there is a metabolic cost (body heat production) associated with excreting N in urine. In young pigs and pigs under heat stress, feed intake and performance will be slightly improved when low protein diets are fed that are properly balanced with amino acids. This should be considered in least cost feed formulation. The calculated net energy (NE) content of a 16% protein corn-soybean meal based diet increases by approximately 1% if 1 kg per tonne of lysine.HCl (and corn) is used to replace SBM, while maintaining the apparent ileal digestible supply of lysine (de Lange and Fuller, 2000). The calculated DE content of the diet is slightly reduced with added lysine (0.1%), while the increase in diet NE content is about four times larger than the GE con-

Table 6. Estimated cost of corn and soybean meal based grower-finisher diets with varying protein levels but balanced for amino acids using synthetic amino acids. The estimated reduction in N excretion with manure as compared to the "standard" corn soybean meal based diet is given as well.

	Corn-SBM-pmx	+ Lysine	+ Lysine +Threonine +Tryptophan	+ Lysine +Threonine +Tryptophan + Methionine
Ingredient comp. (%):				
Corn	74.75	78.58	79.81	84.71
Soybean meal	22.25	18.30	17.00	11.80
Premix	3.00	3.00	3.00	3.00
Lysine.HCl	-	0.12	0.12	0.13
Threonine	-	-	0.02	0.09
Tryptophan / Lysine (15/70)	-	-	0.05	0.23
Methionine	-	-	-	0.04
Calculated content (%):				
Total protein	16.77	15.33	14.86	13.07
DE (Kcal/kg)	3453	3448	3447	3441
Stand. Dig. Lysine	**0.74***	**0.74**	**0.74**	**0.74**
Stand. Dig. Threonine	0.53	**0.47**	**0.47**	**0.47**
Stand. Dig. Tryptophan	0.16	**0.14**	**0.14**	**0.14**
Stand. Dig. Methionine	0.25	0.23	**0.22**	0.24
Stand. Dig. Met + Cys	0.50	0.46	0.45	**0.44**
Stand. Dig. Isoleucine	0.60	0.54	0.52	0.43
Stand. Dig. Valine	0.69	0.62	0.60	**0.52**
Ingredient cost (US$/ton)	106.3	104.5	107.1	117.3

tent of added lysine.HCl. Improving the diet amino acid balance can result in reductions in carcass lean content, particularly when lean tissue growth is not limited by energy intake and when these changes in diet NE content are not considered.

When interpreting published estimates of the optimum amino acid balance, the units in which amino acid levels are expressed, (total diet content; apparent, standardized, true ileal digestible contents), should be considered carefully. For example, based on total or standardized digestible amino acid contents, the optimum threonine to lysine ratio is considerably higher than apparent digestible amino acid contents. This is related to the relatively high threonine content in endogenous gut amino acid losses, which are attributed to the animal when formulating diets based on total or standardized digestible amino acid contents and to the diet when formulating based on apparent digestible amino acid contents (e.g. Nyachoti and de Lange 1997a,b).

Feeding amino acids (balanced protein) more closely to the pigs' requirements

The optimum diet amino acid balance is known to vary with body weight and rate of body protein gain (Wang and Fuller, 1990; Black and Davies, 1991; Baker, 1996; Tuitoek et al., 1997a,b; NRC, 1998; Moughan, 1999). Moreover, we are becoming more aware of the impact of non-protein feed characteristics on amino acid utilization and thus the optimum diet amino acid balance (Moughan, 1999; Zhu and de Lange, 2001). For these reasons, requirements for the essential amino acids, conditionally

Table 7. Available (standardized ileal digestible) amino acid requirements for various body functions that may be used to estimate the growth response of pigs to available amino acid intake.

	Body function			
	Inevitable catabolism	PD**	Physical amino acid losses	
	(% of available intake) [1]	(g AA per 100 g PD) [2]	Minimum gut losses[3] (g/kg DM intake)	Skin & hair losses[4] (mg/kg live BW $^{.75}$)
Lysine	25	7.05	0.40	4.0
Methionine	30	1.97	0.11	0.9
Methionine + Cysteine	30	3.73	0.32	5.2
Threonine	28	3.79	0.61	3.0
Tryptophan	25	1.24	0.14	0.80
Isoleucine	25	3.70	0.38	2.2
Valine	25	4.54	0.54	3.6
N * 6.25	20	100	11.82	93.75

* Some safety margin (5 to 10%) may be added to these estimated requirements when formulating swine diets, to account for inaccuracies in feed preparation and between animal variability in nutrient requirements; even when using a 10% safety margin requirements will be lower than NRC (1998).

** Whole body protein deposition

[1] This represents the minimal inefficiency of using absorbed available amino acid intake to satisfy requirements for the various body functions (Moughan, 1999; Möhn et al., 2000; de Lange et al. 2001; Zhu and de Lange, 2001). For N * 6.25 the value represents inevitable catabolism of a mixture of essential and inessential amino acids.

[2] Adjusted from TMV (1994), Bikker et al. (1994) and Möhn et al. (2000).

[3] Derived from CVB (1998).

[4] Derived from Moughan (1991, 1998) .

limiting amino acids and total N should be represented explicitly (Table 7), as apposed to representing the requirements for a reference amino acid (lysine) and relating the requirements of other amino acids and N to that reference amino acid. The use of factorial approaches (simulation models) to predict amino acid requirements will increase the accuracy with which the animals' requirements can be estimated for individual situations (Stranks et al.,1988; SCA, 1987; Pomar et al., 1991; de Lange and Schreurs, 1995; Lenis and Jongbloed, 1995; NRC, 1998; Moughan, 1999).

The estimates of amino acid requirements for the main biological processing in growing pigs presented in Table 7 may be regarded as a refinement of the NRC (1998) requirements. As a result of replacing 'maintenance' amino acid requirements (NRC, 1998) with physical amino acid losses and associated inevitable amino acid catabolism, the effects of feeding level, BW and protein gain on amino acid requirements are represented (Möhn et al. 2000; de Lange et al. 2001). It is apparent that estimated amino acid requirements are very sensitive to estimates of inevitable amino acid catabolism, rate of protein gain and the amino acid composition of protein gain. Animal, diet and environmental effects on these three aspects of amino acid utilization deserve more attention, both in research and practical diet formulation. For example, in a recent study in our laboratory, the addition of exogenous fiber reduced the utilization of apparent ileal digestible threonine intake for protein gain, while it did not influence the utilization for lysine (Zhu and de Lange, 2001). Moreover, requirements for total N should be considered; when large amounts of synthetic amino acids are included in the diet, N intake may be insufficient N to satisfy requirements for the synthesis of conditionally limiting amino acids (e.g. Kerr and Easter, 1995). Finally, means to establish protein accretion curves in groups of pigs are continuously refined (Schreurs and de Lange, 1995; Schinckel and de Lange, 1996; Schinckel et al., 2002).

Levels of limiting amino acids in pig diets are often higher than levels that are actually required by pigs. Again, these "safety" margins are sometimes very large and expensive. If we adhere to some important principles (*quality control on ingredients, feed preparation and delivery; feeding according to lean growth potentials, gender, body weight and feeding level; minimize feed wastage; maintain a good health status*) both feeding cost and the excretion of N with pig manure can be reduced. Some examples include (Jongbloed and Lenis 1992, Lenis and Jongbloed, 1995; Kornegay, 1996a,b; Kornegay and Verstegen, 2001):

- A reduction in diet Crude Protein (CP) levels by 10% will reduce N excretion with manure by at least 15% (Table 6).
- Improving lean growth rates, as a result of improving lean growth potentials or reducing disease pressure, by 10% will reduce N (and P) excretion in manure by about 10% as well (Jongbloed and Lenis, 1992; Keller, 1980).
- Reducing feed wastage by 5% of feed allowance will reduce N (and P) excretion by about 8%.
- N excretion will be reduced by about 12% when a 16% CP grower diet is replaced by a 14% CP finisher diet, fed between 60 and 115 kg BW (Henry and Dourmad, 1993). Reductions in N excretion, as a result of introducing additional phases will be half that, e.g. 6% by changing from 2 to 3 phases and 3% by moving from 3 to 4 phases. This is reasonably consistent with a 9% reduction in N excretion when a two-phase feeding program was compared to a feeding program in which diets were changed weekly (Chauvel and Ganier, 1996). The latter was achieved by gradually reducing the contribution of the high protein diet in a blend of a high and low protein diet. Similar reductions can be achieved by phase feeding according to changes in P requirements.

Quantification of available amino acid content in swine feed ingredients

As we feed pigs more closely to their requirements, it will become increasingly important that the amino acid availabilities in feedstuffs are accurately determined. It is generally accepted that the ileal amino acid digestibility assay provides reasonable estimates of amino acid availability in the various ingredients. Furthermore, true or standardized ileal amino acid digestibility should be used in feed formulation. Unlike apparent AA digestibility, true ileal AA digestibility values are additive in mixtures of feed ingredients (Nyachoti et al., 1997a,b). However, in heat-treated protein sources, or in ingredients containing large quantities of anti-nutritional factors, the ileal digestibility assay may over-estimate amino acid availability. For example, in case of lysine, the e-amino group can easily react with reducing sugars rendering the amino acid unavailable to the animal (Gall, 1989). Yet, during hydrolyses for conventional amino acid analyses, some of these compounds yield free lysine, suggesting that this lysine is available to the animal. Furthermore, some of these lysine complexes may be absorbed. The latter may explain some of the discrepancies that have been observed between ileal amino acid digestibility and availabilities estimated using more expensive and time-consuming slope-ratio assays. In the latter assays, various inclusion levels of the test ingredient has been related to various animal performance criteria (Batterham et al, 1989; Batterham, 1993; Table 8).

Recently a relatively simple technique has become available to routinely estimate the amounts of ileal digestible, chemically available AA in the various samples of ingredients (Moughan and Rutherfurd, 1996). This technique has a much wider application than the older carpenter lysine assay. Results obtained with this technique, based on the guanidation of lysine to homoarginine, indicates that the extent of heat damage is more severe and of concern in more ingredients than thought previously.

Conclusions

In many areas of the world the contribution of animal agriculture to environmental pollution has become a serious concern. In some countries this has lead to introduction of legislation to reduce mineral excretion by farm animals. Via alternative management practices, the mineral balance on animal farms can be substantially improved. In particular via the use of phytase, synthetic amino acids and by feeding more closely to the animals requirements, the P and N excretion with swine manure can be reduced by up to 50%. Application of these alternative strategies will increase the need for precise feed ingredient evaluation, feed formulation, manufacturing, and

Table 8. Effect of heat on ileal digestibility and availability of lysine in field peas, and on the growth rate and retention of lysine in pigs given diets containing 1.51 ileal digestible lysine/Mcal digestible energy (Batterham, 1993).

	Heat Treatments				
	0^0	110^0	135^0	150^0	165^0
Ileal Digest.	.92	.97	.92	.93	.84
Availability	.96	.71	.77	.56	.47
Growth rate, g/d	498	482	477	450	315
Lys retention, Prop. of intake	.85	.65	.68	.63	.45

delivery. Reducing water spillage from drinkers and reducing the amount of water needed for cleaning can reduce the manure volume. Finally, more basic information is required about the availability of phosphorus in various feedstuffs, the efficacy of exogenous phytase, phosphorus requirements of different (geno-)types of pigs, and about amino acid utilization in finishing pigs.

References

Agricultural Research Council (ARC). 1981. The Nutrient Requirements for Farm Livestock. 3. Pigs. Agricultural Research Council, London.

Baker, D.H. 1996. Advances in amino acid nutrition and metabolism of swine and poultry. In: Nutrient management of Food animals to Enhance and Protect the Environment (Ed. E.T. Kornegay). Lewis Publishers.

Batterham, E.S. 1993, Availability of amino acids in feeds. In: (E.S. Batterham Ed.) Manipulating pig production IV. Australasian Pig Sciences Association, Attwood, Victoria, Australia

Batterham, E.S., L.M. Anderson, D.R. Baigent and R.E. Darnell. 1989. Comparison of the availability and ileal digestibility of lysine in cotton seed and soy-bean meals for grower/finisher pigs. Brit. J. Nutr. 64: 663.

Bikker, P., M.W.A. Verstegen and M. Bosch. 1994 Amino acid composition of growing pigs is affected by protein and energy intake. J. Nutr. 124:1961-1969.

Birkett, S and C.F.M. de Lange. 1998. A simple computer program to calculate the excretion of nitrogen, phosphorus and potassium with manure on individual pig farms based on feed usage and animal flow. 1998 Ontario Swine Research Review. Department of Animal and Poultry Science, University of Guelph, Guelph, ON, Canada.

Black, J.L. and G.T. Davies. 1991. Ideal protein: its variable composition. In: (Ed. E.S. Batterham) Manipulating pig production III. Weribee, Victoria, Australia.

Coelho, M.B. and E.T. Kornegay (Ed.). 1996 Phytase in Animal nutrition and waste management.; A BASF reference manual. pp. 1-728.

CVB (Centraal Veevoederbureau). 1990. Revised table on available phosphorus in feedstuffs for pigs. Centraal Veevoederbureau, Lelystad, The Netherlands (in Dutch).

CVB (Centraal Veevoederbureau). 1998. Table of feedstuffs. Information about composition, digestibility and feeding value. Centraal Veevoederbureau, Lelystad, The Netherlands (in Dutch).

Cromwell, G.L. 1993. An assessment of the bioavailability of phosphorus in feed ingredients for non-ruminants. Proc. Maryland Nutrition Conference. Baltimore, MD. Pp. 146-158.

Cromwell, G.S., R.D. Coffey and H.J. Monegue. 1993. Phytase improves phytate phosphorus utilization in corn-soybean meal for pigs. J. Anim. Sci. 71 (suppl. 1): 165.

Cromwell, G.L. C.C. Calvert, T.R. Cline, J.D. Crenshaw, T.D. Crenshaw, R.A. Easter, R.C. Ewan, C.R. Hamilton, G.M. Hill, A.J. Lewis, D.C. Mahan. E.R. Miller, J.L. Nelssen, J.E. Pettigrew, L.F. Tribble, T.L. Veum and J.T. Yen. 1999. Variability among sources and laboratories in nutrient analyses of corn and soybean meal. J. Anim. Sci. 77:3262-3273.

De Lange, C.F.M. and H.W.E. Schreurs. 1995 Principles of model applications. In. (Ed: P.J. Moughan, M.W.A. Verstegen and M.I. Visser-Reyneveld). Modelling growth in the pig. Wageningen Agricultural University, Wageningen, The Netherlands. pp. 187-208.

De Lange, C.F.M. and M.F. Fuller. 2000 Advances in feed evaluation for pigs. In (Ed. P.J. Moighan, M.W.A. Verstegen and M.I. Visser-Reyneveld). Feed evaluation – principles and practice. Wageningen Pers, Wageningen, The Netherlands. pp. 221-242.

De Lange, C.F.M. A.M. Gillis, and G. Simpson. 2001. The effect of threonine intake and body weight on the efficiency of using threonine for body protein deposition in gilts between 45 and 75 kg body weight. J. Anim. Sci. 79: 3087-3095.

Fan, M.Z., T. Archibald, W.C. Sauer, D. Lackeyram, T. Rideout, Y. Gao, C.FM. de Lange and R. Hacker. 2001. Novel methodology allows simultaneous measurement of true phosphoros digestibility and the gastrointestinal endogenous phosphorus outputs with pigs. J. Nutr. 131: 2388-2396.

Fan, M.Z. and W.C. Sauer. 2002. Additivity of apparent ileal and faecal phosphorus digestibility values measured in single feed ingredients fro growing-finishing pigs. Can. J. Anim. Sci. 82: 183-191.

Gall, M.P.J. 1989. Nutritional and physiological effects of short-term feeding of an early Maillard browned casein to growing pigs. M. Sc. Thesis. Massey University, Palmerston North, New Zealand.

Goss, M.J., D.P. Stonehouse and J.C. Giraldez. 1997. Towards Developing a Decision Support System - progress report of the manure systems group at the University of Guelph. University of Guelph, Guelph, Ontario, Canada. www.oac.uoguelph.ca/ManSys/

Hendriks, W.H. and P.J. Moughan. 1993. Whole-body nutrient composition of entire male and femal pigs depositing protein at maximal rates. Livest. Prod. Sci. 33: 161-170.

Henry Y. and J.Y. Dourmad. 1993. Feeding strategies for minimizing nitrogen outputs in pigs. In: Nitrogen flow in pig production and environmental consequences. Proc. First Intern. Symposium on Nitrogen flow in Pig production and Environmental Consequences. EAAP Publication No. 69. pp. 137.

Jongbloed, A.W. 1987. Phosphorus in the feeding of pigs. Ph.D. Thesis. Agricultural University, Wageningen, The Netherlands.

Jongbloed, A.W. and P.A. Kemme. 1990. Effect of pelleting mixed feeds on phytase activity and the apparent absorbability of P and Ca in pigs. Anim. Feed Sci. Technol., 28: 233-242.

Jongbloed, A.W., H. Everts and P.A. Kemme. 1991. Phosphorus availability and requirements in pigs. In: Recent Advances in Animal Nutrition (Haresign, W. and D.J.A. Cole, Ed.). Butterworths, London.

Jongbloed, A.W. and N.P. Lenis. 1992. Alteration of nutrition as a means to reduce environmental pollution by pigs. Livest. Prod. Sci. 31: 75.

Jongbloed, A.W., Z. Mroz, P.A. Kemme, C. Geerse and Y. van der Honing. 1993. The effect of dietary calcium levels on microbial phytase efficacy in growing pigs. J. Anim. Sci. 71 (suppl. 1): 166.

Jongbloed, A.W., H. Everts, P.A. Kemme and Z. Mroz. 1999. Quantification of absorbability and requirements of macroelements. In (I. Kyriazakis Ed). A Quantitative biology of the pig. CAB International Wallingford, Oxon, UK. pp. 275-298.

Keller, H. 1980. Aktuelle Probleme des Schweizerischen SPF-programmes. Deutsche Tierartzliche Wochenschr. 87: 449.

Kerr, B.J. and R.A. Easter. 1995. Effect of feeding reduced protein, amino acid supplemented diets on nitrogen and energy balance in grower pigs. J. Anim. Sci. 73: 3000-3008.

Kornegay, E.T. (Ed.) 1996a. Nutrient management of Food animals to Enhance and Protect the Environment (Ed. E.T. Kornegay). Lewis Publishers.

Kornegay, E.T. 1996b. Nutritional, Environmental, and Economic Considerations for Using Phytase in Pig and Poultry Diets. In: Nutrient management of Food animals to Enhance and Protect the Environment (Ed. E.T. Kornegay). Lewis Publishers.

Kornegay, E.T. and M.W.A. Verstegen. 2001. Swine nutrition and environmental pollution and odor control. . In A.J. Lewis and L.L. Soutern, Ed) Swine Nutrition. CRC Press Boca Raton, FA. Pp 609-630.

Leech, S. and C.F.M. de Lange. 2001. Variation in phytate and phosphorus content in Ontario corn samples. Can. J. Anim. Sci. (Abstract) 81: 611.

Leech, S. D. and C.F.M. de Lange. 2002. Variation in phytate content in Ontario soybean samples. J. Anim. Sci. (Abstract) 80: in press.

Lenis, N.P. and A. W. Jongbloed. 1995. Modelling animal, feed and environment to estimate nitrogen and mineral excretion by pigs. In: Pig Science. pp. 355-373.

Liu, J., D.W. Bollinger, K. Zyla, D.R. Ledoux and T.L. Veum 1998. Lowering the calcium to total phosphorus ratio increases phosphorus utilization in low phosphorus corn-soybean dies supplemented with microbial phytase from growing-finishing pigs. J. Anim. Sci. 76:808.

MINAS. 2002. MINAS: een verfijnd systeem? (Mineral accounting system: a refined system?). PraktijkKompas. Dutch publication about applied animal production research (in Dutch). Praktijkonderzoek Veehouderij. P.O. Box 2176 8203 AD Lelystad (in Dutch) 16:2. www.pv.wageningen-ur.nl.

Möhn, S. A.M. Gilles, P.J. Moughan and C.F.M. de Lange. 2000. Influence of lysine and energy intakes on body protein deposition and lysine utilization in the growing pig. J. Anim. Sci. 78: 1510-1519.

Moughan, P.J. 1999. Protein metabolism in the growing pig. In (I. Kyriazakis Ed). A Quantitative biology of the pig. CAB International Wallingford, Oxon, UK. pp. 299-332.

Moughan, P.J. and S.M. Rutherfurd. 1996. A new method for determining digestible reactive lysine in foods. J. Agric. and Food Chem. 44: 2202-2209.

Mroz, Z., A.W. Jongbloed and P.A. Kemme. 1994. Apparent digestibility and retention of nutrients bund to phytate complexes as influenced by microbial phytase and feeding regimens in pigs. J. Anim. Sci. 72: 126-132.

National Research Council (NRC). 1998. Nutrient requirements of swine. National Research Council, 9th revised edition. National Academic Press, Washington, DC.

Nyachoti, C.M., C.F.M. de Lange, B.W. McBride and H. Schulze. 1997a. Significance of endogenous gut protein losses in the nutrition of growing pigs: a review. Can. J. Anim. Sci. 77: 149-164.

Nyachoti. M., C.F.M. de Lange and H. Schulze. 1997b. The homo-arginine technique for estimating true ileal lysine digestibility in pig feed ingredients. J. Anim. Sci. 75: 3206-3213.

O'Dell, B.I., A.R. de Boland and S.R. Koirtyohann. 1972. Distribution of phytate and nutritionally important elements among the morphological components of cereal grains. J. Agric. Food Chem. 20: 718-721.

Pomar, C., D.L. Harris and F. Minvielle. 1991. Computer simulation of swine production systems: 1. Modelling the growth of young pigs. J. of Anim. Sci. 69: 1468-1488.

Raboy, V., D.B. Dickensen and F.E. Below. 1984. Variation in seed total phosphorus, phytic acid, zinc, calcium, magnesium and protein among lines of glycine max and G. soy. Crop Sci. 24:431-434.

Schinckel, A.P. and C.F.M. de Lange. 1996. Characterization of growth parameters needed as inputs for pig growth models. J. Anim. Sci. 74:2021-2036.

Schinckel, A.P., J. W. Smith II, M.D. Tokach, S.S. Dritz, M. Einstein, J.N. Nelssen and R.D. Goodband. 2002. Two on-farm data collection methods to determine dynamics of swie compositional growth and estimates of dietary lysine requirements. J. Anim. Sci. 80: 1419-1432.

SCA (Standing Committee on Agriculture). 1987. Feeding standards for Australian livestock. V, Pigs. Editorial and publishing unit, CSIRO, East Melbourne, Australia.

Simons, P.C.M., H.A.J. Versteegh, A.W. Jongbloed, P.A. Kemme, P. Slump, K.D. Bos, M.G.E. Wolters, R.F. Beudeker and G.J. Verschoor. 1990. Improvement of phosphorus availability by microbial phytase in broilers and pigs. Brit. J. Nutr. 64: 525.

Stranks, M.H., B.C. Cooke. C.B. Fairbarn, N.G. Fowler, P.S. Kirby, K.J. McCracken, C.A. Morgan, F.G. Palmer and D.G. Peers. 1988. Nutrient allowances for growing pigs. Res. and Developm. in Agric. 5: 71.

Tuitoek, J.K., L.G. Young, C.F.M. de Lange and B.J. Kerr. 1997a. Body composition and protein and fat accretion in various body components in growing gilts fed diets with different protein levels but estimated to contain similar levels of ideal protein. J. Anim. Sci. 75: 1584-1590.

Tuitoek, J.K., L.G. Young, C.F.M. de Lange and B.J. Kerr. 1997b. The effect of reducing excess dietary amino acids on growing-finishing pig performance: an evaluation of the ideal protein concept. J. Anim. Sci. 75: 1575-1583.

Van der Peet- Schwering, C.M.L., J.W.G.M. Swinkels and L.A. de Hartog. 1993. Microbial phytase in weanling diets of pigs. J.Anim. Sci. 71 (suppl. 1): 250.

Verstegen, M.W.A., L.A. den Hartog, G.J.M. van Kempen and J.H.M. Metz (Ed.). 1993. Nitrogen flow in pig production and environmental consequences. Proc. First Intern. Symposium on Nitrogen flow in Pig production and Environmental Consequences. EAAP Publication No. 69. pp. 1-493.

Wang, T.C. and M.F. Fuller. 1990. The effect of plane of nutrition on the optimum dietary amino acid pattern for growing pigs. Anim. Prod. 50:155.

Whittemore, C.T. and R.H. Fawcett. 1976. Theoretical aspects of a flexible model to simulate protein and lipid growth in pigs. Anim. Prod. 22:87.

Yi, Z. and E.T. Kornegay. 1996 Evaluation of Response criteria for assessing biological availability of phosphorus supplements in swine. In (Coelhe, M.B. and E.T. Kornegay Ed.) Phytase in Animal nutrition and waste management; A BASF reference manual. pp. 137-144.

Zhu, C. L. and C.F.M. de Lange. 2001. Influence of graded levels of pectin on the utilization of dietary threonine and lysine for body protein deposition. Can. J. Anim. Sci. 81:610.

Mass Balance
It's Importance in Nutrient Management

Gretchen Myers Hill , Professor, Animal Science Department
Michigan State University, East Lansing, MI 48824

Summary

Mass balance of nutrients is the difference between inputs and outputs and involves the nutrients that are brought onto a farm and those which leave. Nutrients may arrive as purchased grains, pre-mixes, feeds, animals or the nitrogen (N) fixed by a legume crop or dissolved in irrigation water. The sale of animals, animal products such as milk, grains, compost, manure, etc. constitutes the output. In the past we have thought of these balances uniquely for either phosphorus (P) or N, but today we realize we need to be concerned with many other mineral elements and electrolytes such as potassium (K), copper (Cu), zinc (Zn), magnesium (Mg), iron (Fe), etc. The difference between input and output for each of these parameters can be thought of as an indication of environmental and animal health risk.

Thus, nutrient management strategies must be implemented within farms and even corporations to limit the negative risk and improve the benefit to the health of our animals, personnel and environment.

Introduction

As Nelson (1999) said, "The role of nutrient management in livestock systems takes on new meaning as producer and the public together consider economic and non-economic issues. Until recently, landowners and land managers had relative freedom for application and redistribution of mineral elements." Today things are different! With the need to prevent contamination of streams and build up of phosphorus (P) in soils, livestock producers have been "allowed" to place a known and maximum amount of P on fields. However, this technique is far from accurate and fair since book values are often used to estimate P in manure, and all soils are assumed to be equal. Nitrogen (N) as with P is often estimated in waste management plans with the amount that volatilizes being a guess since waste handing facilities and techniques of handling influence the true N available for utilization by crops. Now those raising forages for use by ruminants have great concerns about the amount of potassium (K) in soils, but little is information is known about its interaction with other nutrients. Copper (Cu) and zinc (Zn) have been found to be building up in soils as deep as three feet, yet the unknown consequences are a guess. Hence, the advent of the mass balance system to stop continual build up of nutrients and more accurately reflect the total farm enterprise is a tool worth considering.

Defining the Task

Traditionally, nutrients have been imported onto livestock operations relative to the needs of the animals in the enterprise. Koelsch and Lesoing (1999) suggested that there are less apparent physical and economic ties to crop production in a livestock operation. We purchase premixes, complete feeds or feedstuffs according to the needs of the animals in our enterprise. A good example in a swine operation is the purchasing of nursery diets. Many small to medium size farms grow corn and soybeans, buy premixes and do their own on farm mixing. However, the mini pellet for the newly weaned pig requires access to many feedstuffs that are used in small quantities, and the diet components are best pelleted. Therefore, this (these) diets are purchased.

Our limited data from balance trials and body composition studies indicates that most nutrients fed to animals are not marketed as milk or meat, but remain behind as manure or are volatilized into the environment. A finishing pig may retain 35 to 45% of the N fed while a more efficient growing nursery pig may retain 50 to 70% of the Zn fed. In agriculture, we typically view manure nutrients as being "recycled" into crops. In days gone by, this practice was a system that had to be "in balance" prior to the use of inorganic fertilizers and "crop or livestock only" enterprises. However today as we try to maximize crop yields with inorganic fertilizers and do not know the true content of the waste products of the livestock enterprise as they are knifed into or spread onto the land, many insults to the soil occur. A dairy nutritionist will complain about the high K content of the alfalfa hay due to the spreading of the hog manure on an alfalfa field, but he and the producer do not delete the potash from the inorganic fertilizer that is applied to increase yield. Mass balance might help to solve this problem.

Information Needed

For a mass balance system to accurately reflect the enterprise, we need to know the source and amount of input and output nutrients. The more accurate this information is the more accurate the mass balance will be for the nutrients of interest. It is easy to obtain the nutrient content of purchased feeds, pre-mixes and fertilizers. We use their content as criteria for purchase. However, how can you accurately know the nutrient content of purchased seed stock or seed grain? If you have it analyzed, you will not have it for breeding or production. Obviously, we must depend on "book" values, and few of these are available let alone accurate for today's livestock. These estimates decrease the accuracy of the inputs in the mass balance system. Irrigation water will need to be analyzed for content, and the amount of N fixed by a legume crop will need to be estimated or determined by a laboratory.

Similarly, content of most outputs is seldom accurate. We might be able to estimate the amount of N that leaves the farm when we market finishing pigs by using the lean content of the carcass and assuming that the protein content is the amount of N multiplied by 6.25. What about the P, Zn, Cu, Fe, etc. content of those pigs? An even greater mystery is the body composition of sows and feeder pigs. Again, perhaps book values can be used for N, but they seldom reflect the body composition of today's hogs. The mineral content of hogs leaving our swine enterprises is at best an educated guess! The most recent whole body P data is from 1968 (Martin et al., 1968), and they suggest that P is 0.47 to 0.56% of body weight. Today, scientists are University of Missouri, Purdue University and Michigan State University are completing whole body composition analysis of current genetics used in the swine industry. To accurately reflect the output portion of mass balance, we also need to analyze the manure and crops including hay or rented pasture that are sold off the farm.

Interpretation

The nutrient balance including nutrients in the inventory can be used to indicate the risk to the health of the animals, producers and environment. While P imbalance might indicate a risk to streams and waterways, it is not clear what a Cu imbalance means. Anderson et al. (1991) reported that manure with an average of 1300 mg of Cu/kg of wet manure increased the soil content to 325 kg Cu/Ha over an 11-year period. However, the corn yield and Cu concentration of the grain and leaf were not altered. What might happen with a different soil type, corn cultivar or another crop? High concentrations of Zn in the soil are toxic to peanuts. How much is useful or toxic to corn? With N we have the volatilization in our buildings and from anaerobic lagoons and surface application of manure. Nitrogen balance may not accurately reflect these losses yet the environment is affected.

Koelsch and Lesoing (1999) summarized nutrient balance on 33 farms and found that the "magnitude of nutrient inputs, managed outputs and imbalance increased with size." They noted that if a farm had fewer livestock numbers and a large land base, they were removing more P by cropping than being added by commercial fertilizers. Some producers with large numbers of animals were in neutral P balance by selling manure off the farm. They noted that a livestock enterprise needed 0.6 ha of cropped land per animal unit to be in negative P balance. On the input side, purchased animal feeds bring in 33 to 77% of the total N and 62 to 71% of the total P input on a livestock farm. Specifically on swine farms, purchased P for feed contributed approximately one third of the total farm input of P (Koelsch and Lesoing, 1999). The contribution of the crop or livestock enterprise to the output of a nutrient is reflected by the size of the livestock portion of the enterprise. For example, farms with more than 2,500 animal units have over 65% of the N output contributed by animal products while 54 to 72% of the N output is from marketed crops when animal units are less than 2,500.

Summary

As expected, neutral and accurate nutrient balance is best achieved by:

(1) Analysis of inputs and outputs when ever possible and hence reduced reliance on "book" values

(2) Careful management of the use of manure nutrients in crop production by accurate application for a crops' needs and export or sale of excess manure nutrients

(3) Using technologies of today and the future to distribute nutrients to areas of need such as using exogenous and endogenous phytase to improve the availability of P to nonruminants and growing crops with inherent increased available P.

References

Anderson, M. A., J. R. McKenna, D. C. Martens, S. J. Donohue, E. T. Kornegay, and M. D. Lindemann. 1991. Long-term effects of copper rich swine manure application on continuous corn production. Commun. Soil Sci. Plant Anal. 22: 993-1002.

Koelsch, R., and G. Lesoing. 1999. Nutrient balance on Nebraska livestock confinement systems. J. Anim. Sci. 77(Suppl. 2): 63-71.

Martin, T. G., E. G. Stant Jr., W. V. Kessler, M. D. Judge, and J. E. Christian. 1968. Associations of body potassium, chemical position and carcass measurements with fat:lean composition determined by physical separation. Body Composition in Animals and Man. Natl. Acad. Sci. Publ. 1598: 428.

Nelson, C. J. 1999. Managing nutrients across regions of the United States. J. Anim. Sci. 77(Suppl. 2): 90-100.