Effects of Dietary Manipulation on Pig Performance, Manure Composition, Hydrogen Sulfide and Ammonia Levels in Swine Buildings

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Introduction

Excess excreted nutrients and emissions from swine production facilities continue to draw public attention as the rural-urban interface narrows and the threat of environmental impact grows. N-containing compounds originating from intensive agriculture are contributing to a decline in forest health and species diversity in the Netherlands (van der Eerden et al., 1998) and increased nitrate concentrations in groundwater in Canada (Zebarth et al., 1998). In swine buildings, low levels of NH_3 (25 ppm) induced nasal irritation and depression of growth in pigs (Urbain et al., 1994), while Zhang et al. (1998) reported that air quality in a confinement swine building can cause acute respiratory responses in humans. Additionally, phosphorus accumulation in the soil could pose a threat to both groundwater and surface water quality.

Manipulation of swine diets has been shown to be effective at decreasing N excretion of pigs by feeding diets that contain reduced levels of crude protein (CP) supplemented with essential synthetic amino acids (Gatel and Grosjean, 1992). Urinary N is reduced dramatically while fecal N remains relatively constant (Kerr and Easter, 1995), which limits NH_3 emission (Canh, 1998). Feeding fermentable carbohydrates such as soybean hulls has been used to effectively reduce the ammonia emission from manure. The use of the phytase enzyme has been shown effective in liberating approximately 30% of the previously unavailable P from its phytic acid form in cereal grains. Spencer et al. (2000) reported that low-phytate corn (Lpa-1) contains at least 5 times as much available P as normal corn with a bioavailability near 62%. Recent research has indicated that there is a tendency for lower hydrogen sulfide levels in buildings where pigs are fed diets with lower sulfur content.

Materials and Methods

Experimental Design

Two experiments were conducted to determine the effect of diet on growth performance, aerial ammonia, aerial hydrogen sulfide, odor, and nutrient excretion. Experiment 1 consisted of 80 grow-finish pigs (initial BW = 176.8 lbs) placed in two identical, environmentally controlled rooms (separate manure storage and ventilation systems) where they were allotted by ancestry, sex and weight. Each room contained 10 pens with pigs housed at 2 pigs/pen with one nipple waterer and a two-hole feeder on woven wire floors (8.6 ft^2/pig). There were 2 replications (40 pigs/rep) with treatments rotated between rooms. Pigs were weighed and feed consumption recorded at 0, 3, and 6 weeks. Pigs were ultrasonically scanned (longitudinally) for backfat thickness and loin depth at the tenth rib on weeks 0, 3 and 6 using an Aloka 500 real-time ultrasound machine. Manure storage pits were initially charged with third-stage lagoon flush water until the pit floor was completely submerged. Baffles in the air handling system were set to deliver a constant rate of incoming air into the room at a ratio of 75% recycled to 25% fresh air. Temperature was kept constant between rooms (68°F) with water chillers and heating coils in the air handling system. Experiment 2 consisted of 100 grow-finish pigs (initial BW = 181.7 lbs) with the same experimental procedures, but only 5 pens per room with 5 pigs/pen (50 pigs/rep) for 2 replicates with treatments alternating rooms.

Diets

Both experiments were for six weeks. In experiment 1, two diets were fed (Tables 1 and 2): a control diet (11.5% CP, .60% lysine [Lys]), and a reduced CP diet (8.25% CP, .57% Lys; HRP) formulated with added synthetic amino acids, high-available phosphorus (HAP) corn, 5% soybean hulls, low-sulfur trace mineral premix (replacing sulfur sources with either carbonate, chloride or oxide sources) and 272 phytase units of activity/ton from Natuphos phytase. Diets were formulated to be isocaloric and equal in available lysine, and met or exceeded all other nutrient recommendations for finishing swine (NRC, 1998). The HRP diets were formulated to NRC requirements for methionine+cysteine, tryptophan, threonine, and isoleucine. In experiment 2, two additional diets were formulated to better match the higher amino acid requirements of gilts in the trial. These included a control diet (12.6% CP, 0.63% Lys) and an HRP diet (9.35% CP, 0.60% Lys). The diets described for experiment 1 were fed to barrows in experiment 2.

Sample collection and analysis

Four-hour aerial ammonia concentration (AAC) samples were taken with Dräger long-term diffusion tubes at pig height in the front, middle and back of the room and from the exhausting room air between 0700 and 1100 hours at weeks 4 and 6. Hydrogen sulfide levels were analyzed at Iowa State University from room air collected at these same times and locations in plastic bags designed for determination of odorant concentration. Pit depth was recorded and representative pit samples were collected at 0, 3, and 6 weeks for calculation of pit volume and composition. Dry matter was analyzed by drying overnight at 217°F. Determination of pH was made with a glass electrode (Corning 130 pH meter). Nitrogen content of the manure was determined by the Kjeldahl procedure, and phosphorus content was determined colormetrically (Milton-Roy Model 301 UV/light spectrophotometer).

Statistical analysis

The results of both experiments were pooled due to the similarities of diets and design. For growth and carcass measurements, pen was considered the experimental unit and the replicate was considered a random effect. Dietary treatment and sex effects along with their interaction were tested against the residual error term. Each experiment was also analyzed separately with main effects of diet, sex, replicate and their interactions. Room was the experimental unit for pit composition, AAC, and hydrogen sulfide. For all measures of pit composition, AAC and hydrogen sulfide, dietary treatment was the main effect with replicate used as a blocking factor and was tested for significance against the residual error term. All criteria were analyzed using the GLM procedure of SAS (1996).

Results

The growth performance of pigs is listed in Table 3 by main effects of diet and sex. A numerical increase in final weight was observed for pigs fed the control diet (4.4 lbs heavier; P<.12). During the initial period (weeks 0-3), pigs fed control diets had 5.6% higher average daily gain (ADG; P<.007) and were 6.2% more efficient (P<.005). During weeks 0-3, barrows consumed nearly 0.5 lb more feed per day than gilts (P<.03), and had 0.67 and 0.59 lb/day higher ADFI for weeks 3-6 and weeks 0-6, respectively. There was a tendency for pigs fed the control diet to have higher ADG for the overall trial (1.74 vs. 1.63 lbs/day; P<.12). Carcass measurements of 10^{th} rib backfat and loin depth showed no differences between dietary treatments, but gilts tended to have less backfat and greater loin depth than barrows.

Serum urea nitrogen (SUN) levels were lower in those pigs fed HRP diets at both weeks 3 and 6. This indicates that these pigs had less excess amino acids to metabolize and excrete.

Growth performance of each experiment is depicted in Table 4. In general, the pigs fed control diets in Exp. 1 were heavier, had higher ADG, were more efficient, had larger loin depths at week 6, less accumulation of backfat and higher SUN values. In contrast, the pigs fed control diets in Exp. 2 were nearly identical to pigs fed HRP diets in every respect except for having higher SUN values.

The aerial ammonia concentration (AAC) is listed in Table 5. At week 4, the room air from pigs fed HRP diets had less ammonia and these pig rooms were also exhausting less ammonia. These trends strengthened by week 6, with a 48.7% reduction in AAC (P<.03) from room air and 49.8% reduction in the exhaust air (P<.04) for pigs fed HRP diets. The hydrogen sulfide (HS) levels measured at both week 4 and 6 in both the room and exhaust air showed a numerical decrease in HS levels in rooms where pigs were fed HRP diets (Table 6). At week 6 in the room air, the hydrogen sulfide levels were actually 48% lower in the rooms where HRP diets were fed.

The composition of stored manure is shown in Table 7. By week 3, there is a 31% reduction in total nitrogen (TKN), 30.4% lower ammonium nitrogen (NH_4-N), and 37.8% less phosphorus in the stored manure from pigs fed HRP diets. At week 6, the stored manure from pigs fed HRP diets had 26.9% less TKN, 29.5% lower NH_4-N, and 51.7% less excreted P. In Table 8, the actual quantities of these nutrients are calculated based on the quantity of manure in storage and the concentration of each compound. It shows that by feeding HRP diets, the total quantity of TKN, NH_4-N and P can be reduced by 28.5%, 31.2% and 53.7%, respectively.

The pH of the stored manure is described in Table 9. From an initial value of slightly more than 8, a rapid decline in pH can be seen over time with each of the diets. However, the stored manure from pigs fed HRP diets had a lower pH at week 3 (7.19 vs. 7.6; P<.01) and week 6 (7.00 vs. 7.27; P< .055), and had a larger decline (-1.09 vs. -.75 units; P<.056).

Discussion

The initial work with reduced crude protein diets surfaced with the advent of synthetic amino acids. Nutritionists saw the economical value of replacing soybean meal with synthetic lysine. Pigs were still given diets that adequately met their requirements for amino acids but had fewer excesses in their diets. More recently, the focus has turned from economics to environmental concerns. The relationship between dietary crude protein and nitrogen excretion was explored in a review by Kendall (2000). When diets are initially lowered in crude protein by 1 or 2 percentage units, there is a sharp initial decline in N excretion (15 to 20%); for the next 4 percentage units, there is a 5.6 % decrease in N excretion for growing and finishing pigs. The maximum reduction in nitrogen excretion appears to be near a 45 to 50% reduction.

Some of the long held stigmas associated with feeding diets that are lower in crude protein content are that pigs will not gain as well and that they will have poorer carcass characteristics. Pigs fed reduced CP diets had similar growth performance to those fed control diets (Kerr and Easter, 1995), while others report a decrease in growth rate (Tuitoek et al., 1997), mostly attributed to amino acid deficiencies. Pigs fed reduced CP diets tend to have higher fat accretion (Kerr and Easter, 1995), credited in part to an increase in net energy (NE) content of these diets.

As was shown in Table 4, the inferior performance of pigs fed HRP diets in Exp. 1 exposed the need to feed split-sex diets. Though not statistically significant, there was an apparent trend for poorer performance for pigs offered HRP diets. This appeared to be more evident in the gilts than the barrows. Pigs fed HRP diets had a smaller loin depth and accumulated more backfat. These facts all point towards amino acid limitations in the test diet, which is believable because the amino acid profile of the HRP diet in Exp. 1 was at minimal levels, potentially limiting the performance of gilts and high lean growth barrows. The results from Exp. 2 indicate that by adding a diet to better meet the needs of the gilts, the performance of pigs offered the HRP diets could be restored to levels close to that of pigs fed control diets. Not only was the ADG improved, but also the feed efficiency and carcass characteristics.

Aerial ammonia levels were decreased rather dramatically in rooms where HRP diets were fed. This is not surprising considering the extent the dietary crude protein was lowered, and is consistent with published data from Purdue and other institutions. The hydrogen sulfide levels were numerically lower at each time period and location. By reducing the level of mineral sulfates and sulfur amino acids in the diet, the hydrogen sulfide levels have also declined. Previous research at the University of Minnesota and Purdue agree with this conclusion, but further study of reducing dietary sulfur will be necessary to determine if these effects are truly real.

There was a greater pH decline in stored manure from pigs fed HRP diets than those fed control diets ($P<.056$). This is consistent with findings by Canh (1998) in diets containing fermentable substrates and in reduced crude protein diets (Sutton et al., 1998; Canh, 1998). In these experiments, the decline in pH has been partly attributed to the decrease in NH_4-N content of the slurry as well as increased VFA concentration of the slurry from the fermentation of carbohydrates (Canh, 1998). Another alternative is that the acid-base balance of the animal is altered by the dietary manipulation, thus increasing net acid excretion by the pig (Canh et al., 1998).

The DM content of slurry from rooms fed HRP was numerically higher, and these rooms had less total manure volume. This is similar to findings by Kay and Lee (1997), where pigs fed reduced crude protein diets consumed less water, therefore creating lower slurry volumes and a higher percentage of solids in the manure. In a small way, this reduction in quantity of slurry could benefit producers by reducing manure application volume.

There was considerable reduction in TKN, NH_4-N and P from stored manure. The manure from pigs fed the HRP diets is more dilute in its nutrient concentration, allowing for less acres required for manure application. If a producer is applying manure to meet the nitrogen need of their crops, less P is associated with the manure, reducing the possibility of over-application of P. If a producer is applying manure to meet the P needs of their crops, with a 53% reduction in P content of the manure, they would only need 53% of their current land base to apply manure. This should allow pork producers to have more freedom in designing manure management plans that better meet the need of their crops without over-applying nutrients.

To complete the nutrient cycle, manure must be applied to land for assimilation by plants for growth. Misselbrook et al. (1997) observed a 60% decrease in NH_3 emissions following landspreading of manure from pigs fed reduced crude protein diets. There was also a 73% reduction in the denitrification losses from these plots over a 51-day period, creating a more efficient recovery of applied N into herbage. When looking at the whole farm nutrient balance, reduced crude protein and P diets would appear to be a more efficient use of inputs into swine production and a more environmentally responsible choice.

Implications

This research suggests that reducing the dietary CP, including 5% soybean hulls, utilizing HAP corn, and adding phytase and reduced mineral sulfates to diets will lower aerial ammonia concentration and aerial hydrogen sulfide levels in room and exhaust air. The pH of the stored manure can be lowered along with the quantity of TKN and NH_4-N, with a dramatic decrease in P content. The environmental impact of swine production should be lowered by feeding diets formulated in similar manners, both from emission but also from application of nutrients. In a commercial setting, recommendations should not be as strict as the diets in the current study. This should alleviate any concern over amino acid deficiencies and allow for maximum growth performance with a large percentage of the environmental benefit.

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Table 1. Ingredient composition of experimental diets.

	Exp. 1 & 2 (barrow)		Exp. 2 (gilt)	
Ingredient, %	Control	HRP[a]	Control	HRP[a]
Corn	87.80	--	84.71	--
High-available P corn	--	90.47	--	87.16
SBM-48%	8.71	--	11.94	3.32
Soybean hulls	--	5.00	--	5.00
Yellow swine grease	1.00	2.34	1.00	2.40
Dicalcium Phos.	1.10	--	1.03	--
Limestone	0.79	1.18	0.79	1.14
Salt	0.25	0.25	0.25	0.25
Purdue Swine Vit. Premix[b]	0.10	0.10	0.10	0.10
Purdue Swine TM Premix[c]	0.05	--	0.05	--
Low Sulfur TM Premix[d]	--	0.05	--	0.05
Natuphos	--	0.05	--	0.05
Se 600 Premix	0.05	0.05	0.05	0.05
Lysine-HCl	0.15	0.40	0.084	0.33
L-Threonine	--	0.072	--	0.087
L-Tryptophan	--	0.040	--	0.036
DL-Methionine	--	--	--	0.010
L-Isoleucine	--	--	--	0.014

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates.

[b] Provides per lb of diet: 1100 IU Vitamin A, 110 IU D3, 8 IU Vitamin E, .365 mg Menadione, .006 mg B12, 1.28 mg Riboflavin, 4.0 mg Pantothentic Acid, 6.0 mg Niacin.

[c] Provides per lb of diet: 48 ppm Zn, 48 ppm Fe, 6 ppm Manganese, 4.5 ppm Cu, .16 ppm I.

[d] Iron carbonate replacing ferrous sulfate, zinc oxide replacing zinc sulfate, manganese oxide replacing manganese sulfate, and copper chloride replacing copper sulfate formulated to provide equal quantities of available minerals.

Table 2. Calculated composition of experimental diets.

	Exp. 1 & 2 (barrow)		Exp. 2 (gilt)	
	Control	HRP[a]	Control	HRP[a]
ME (Kcal/lb)	1532	1534	1532	1534
Crude protein, %	11.5	8.25	12.6	9.35
Lysine %	.60	.57	.63	.60
Calcium, %	.60	.50	.60	.50
Phosphorus, %	.50	.26	.50	.26
Available Phosphorus, %	.26	.16	.26	.16
Digestible amino acids				
Lysine, %	.477	.477	.510	.510
Threonine, %	.335	.300	.340	.320
Methionine + Cysteine, %	.379	.300	.377	.310
Tryptophan, %	.076	.080	.090	.090
Isoleucine, %	.404	.270	.404	.280

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates.

Table 3. Effect of diet on body weight, average daily gain (ADG), average daily feed intake (ADFI), feed efficiency (G:F), serum urea nitrogen (SUN), and 10th rib backfat and loin depth of finishing swine.

Main Effect	Dietary Treatments[a]		Sex			Significance		
	HRP	CONT	Barrow	Gilt	CV	Diet	Sex	Diet*Sex
Initial wt, lb	179.3	179.2	179.5	179.0	4.8	.91	.75	.61
Final wt, lb	247.9	252.3	253.1	247.2	5.0	.12	.20	.81
Weeks 0-3								
ADG, lb/day	1.59	1.68	1.70	1.58	15.0	.007	.19	.80
ADFI, lb/day	5.80	5.77	6.04	5.54	8.6	.81	.03	.93
G:F	.274	.291	.280	.285	10.3	.005	.55	.43
Weeks 3-6								
ADG, lb/day	1.66	1.81	1.80	1.67	16.4	.23	.38	.79
ADFI, lb/day	6.21	6.45	6.66	5.99	10.5	.53	.003	.87
G:F	.266	.280	.269	.278	10.1	.41	.62	.32
Weeks 0-6								
ADG, lb/day	1.63	1.74	1.75	1.63	11.2	.12	.21	.89
ADFI, lb/day	6.00	6.11	6.35	5.76	8.3	.62	.004	.99
G:F	.271	.286	.275	.281	6.1	.20	.64	.40
SUN, mg/dL								
Week 3	4.83	7.58	6.22	6.18	18.3	.001	.74	.66
Week 6	3.94	6.04	5.32	4.66	18.0	.03	.12	.60
10th rib backfat, in								
Week 0	.49	.51	.54	.47	16.2	.30	.15	.78
Week 6	.71	.71	.77	.65	14.7	.94	.07	.60
Change	.22	.20	.24	.19	35.6	.56	.002	.46
Loin depth, in								
Week 0	1.81	1.83	1.78	1.86	7.6	.72	.11	.77
Week 6	1.95	2.00	1.93	2.01	5.6	.23	.07	.25

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates; CONT = Control diet.

Table 4. Effect of diet on body weight, average daily gain (ADG), average daily feed intake (ADFI), feed efficiency (G:F), serum urea nitrogen (SUN), 10th rib backfat and loin depth of finishing swine.

Experiment	Exp. 1		Exp. 2		Significance (Diet)	
Diet[a]	HRP	CONT	HRP	CONT	Exp. 1	Exp. 2
Initial wt, lb	177.0	176.7	181.6	181.7	.92	.99
Final wt, lb	245.1	252.8	250.8	251.9	.05	.88
Weeks 0-3						
ADG, lb/day	1.62	1.72	1.56	1.64	.22	.40
ADFI, lb/day	5.98	5.92	5.62	5.63	.68	.98
G:F	.270	.290	.278	.291	.06	.13
Weeks 3-6						
ADG, lb/day	1.61	1.91	1.72	1.70	.006	.83
ADFI, lb/day	6.33	6.63	6.09	6.27	.22	.44
G:F	.249	.287	.283	.273	.001	.19
Weeks 0-6						
ADG, lb/day	1.62	1.82	1.64	1.67	.004	.73
ADFI, lb/day	6.14	6.27	5.86	5.95	.42	.71
G:F	.261	.289	.281	.282	.001	.79
SUN, mg/dL						
Week 3	4.98	7.89	4.67	7.26	.001	.001
Week 6	4.62	7.62	3.26	4.81	.001	.005
10th rib backfat, in						
Week 0	.48	.51	.50	.52	.29	.65
Week 6	.71	.69	.72	.74	.67	.63
Change	.23	.18	.21	.22	.09	.86
Loin depth, in						
Week 0	---	---	1.80	1.79	---	.76
Week 6	1.87	1.97	2.03	2.03	.004	.94
Change	---	---	.22	.24	---	.72

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates; CONT = Control diet.

Table 5. Effect of diet on four-hour aerial ammonia concentration (AAC, ppm) in room and exhaust air.

Week	4		6	
Location	Room	Exhaust	Room	Exhaust
Control	19.6	29.6	21.5	28.1
HRP[a]	9.9	12.9	10.8	14.1
Significance	.04	.09	.03	.04
CV	26.0	29.5	21.0	25.5

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates.

Table 6. Effect of diet on hydrogen sulfide concentration (AHS, ppm) in room and exhaust air.

Week	4		6	
Location	Room	Exhaust	Room	Exhaust
Control	1.02	.78	1.27	1.07
HRP[a]	.77	.63	.66	.67
Significance	.23	.32	.12	.24
CV	26.1	20.5	28.3	34.0

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates.

Table 7. Effect of diet on stored manure dry matter (%DM), total nitrogen (TKN), ammonium nitrogen (NH_4-N), and phosphorus (P) for weeks 3 and 6 on a DM basis.

	Week 3				Week 6			
		% of DM				% of DM		
	% DM	TKN	NH_4-N	P	% DM	TKN	NH_4-N	P
Control	.76	24.8	22.7	2.83	1.03	23.8	21.7	3.09
HRP[a]	.77	17.1	15.8	1.76	1.14	17.4	15.3	1.49
Significance	.95	.007	.001	.24	.58	.005	.02	.02
CV	17.9	3.8	.56	34.0	23.3	6.0	8.6	19.0

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates.

Table 8. Effect of diet on the accumulation of total nitrogen (TKN), ammonium nitrogen (NH_4-N), and phosphorus (P) between weeks 0 and 6 in stored manure (1592 lb of liveweight gain).

	Accumulated quantity (lb)		
	TKN	NH_4-N	P
Control	44.2	40.0	5.73
HRP[a]	31.6	27.5	2.65
Significance	.003	.001	.004
CV	4.8	3.7	12.3

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates.

Table 9. Effect of diet on pH content of stored manure.

	Pit pH			
Week	0	3	6	pH change
Control	8.02	7.60	7.27	-.75
HRP[a]	8.09	7.19	7.00	-1.09
Significance	.15	.01	.055	.056
CV	.63	.57	1.73	17.2

[a] HRP = Reduced crude protein diet with 5% soybean hulls, high-available P corn, phytase and reduced mineral sulfates.