Reduction of Ammonia Emission and Phosphorus Excretion in Laying Hen Manure Through Feed Manipulation

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Abstract

Feed strategies to reduce the levels of ammonia (NH_3) emitted from, and phosphorus excreted in laying hen manure have been studied, with limited success. Feeding urease/uricase-inhibiting materials (Kim, et al, 2004), feed reformulation to reduce excess crude protein (CP) inputs (Elwinger, et al, 1996), and enzymes added to feed to reduce ammonia emissions have been tested. Addition of "acidogenic" compounds (materials which induce acidic conditions in manure at the point of excretion) to feed have also been tested in pigs (Kim, et al, 2001) and hens (Van Ooijen, US Patent 5,562,916).

Feed reformulation using a combination of acidogenic materials and ammonium (NH_4^+) ion scavenging materials preloaded with phosphate-reactive compounds, coupled with crude protein reductions, provide significantly higher ammonia emission reductions than have been noted previously. Reductions in excreted phosphorus and the ratio of soluble to total phosphorus in manure provide an additional environmental benefit. This, coupled with increases in nitrogen retained in the manure, also substantially improves the N:P ratio of laying hen manure used as fertilizer.

Keywords. Ammonia emission, phosphorus excretion, phosphorus solubility, feed manipulation, acidogenic, zeolite.

Introduction

Ammonia is a large component of the gaseous emissions from laying hen operations. For this reason, measures to control emissions at egg-laying operations generally incorporate strategies to reduce ammonia volatilization. The feed system described is of particular utility in terms of reducing ammonia emissions from both caged laying facilities and free-range laying facilities.

In addition to ammonia's role as a component in nuisance odors, high levels of gaseous ammonia adversely affect animal health and the safety of people working in these environments. For example, chickens and turkeys continuously exposed to 20 parts-per-million (ppm) ammonia vapors exhibit significant respiratory tract damage after only six weeks (Anderson, et al, 1964). Chicks exposed to 20 ppm ammonia for 72 hours are much more susceptible to Newcastle Disease than chicks reared in ammonia-free environments (Anderson et al., 1964). Ammonia levels in excess of 100 ppm in the atmosphere in a layer house can also affect egg production (Deaton, et al, 1982). From a global perspective, ammonia emissions also play a key role in acid rain formation.

Watershed impairment through eutrophication is often linked to soluble P. Additionally, nitrogen is a causative factor in eutrophication, primarily through wet/dry deposition of dissolved gaseous or fine particulate materials.

Ammonia in poultry manure is generated by enzymatic conversion of uric acid to ammonia via the action of uricase, urease, and other enzymes. Laying hen manure exhibits a basic pH, so the predominant form of nitrogenous emission is ammonia. Under acidic conditions, ammonia protonates to form ammonium which is significantly less volatile than ammonia. Manipulating feed by introducing an acidogenic material to force protonation of ammonia results in somewhat reduced ammonia emissions in laying hen manure. Examples of acidogenic feed materials are gypsum (calcium sulfate, $CaSO_4$), calcium chloride, calcium phosphate, and ammonium benzoate.

Gypsum has been tested as an alternative to limestone (calcium carbonate, $CaCO_3$) as a calcium source in laying hen diets. Gypsum was found not to reduce hen performance if the amount of gypsum substituted in lieu of limestone was kept below approximately 66%, and the limestone particle size was kept sufficiently large to slow the release of calcium in the digestive system (Keshavarz, 1991).

With regard to ammonium formation, the pH-induced protonation is reversible. As the pH of the manure rises due to the effect of carbonates generated during formation of ammonia or present in the diet as undigested minerals, free ammonium will deprotonate to form ammonia, which will begin to offgas.

Experiment 1, Acidogenic Diet Effects on Manure Ammonia Emissions

To counteract reversibility, acidogenic feeds may rely on reactions between acid anions and ammonium to form stable compounds. In practice, however, these reactions do not significantly reduce overall ammonia emission rates over time. To illustrate this effect, gypsum was substituted for a portion of the limestone in laying hen diets to reduce the pH of the manure from about 8.3 standard units (SU) to a slightly acidic pH (<7 SU) level. In this diet, ground (<10 mesh/>100 mesh) gypsum was the source of 45% of the total calcium added to the diet. For comparison purposes, a non-acidogenic industry standard diet containing 18.8% crude protein (CP) was used to create a baseline for manure ammonia emissions.

In order to determine the effects of dietary modifications on ammonia emissions, emissions from manure resulting from hens being fed various diets were analyzed. Eight (8) units consisting of 20 Hyline W36 hens/unit, where each unit was further separated into 5-bird pens, were used for the reduced emission diet trials. Each unit received either an industry standard feed formulated to meet the nutritional needs for that age of bird, or the amended feed being tested. Each feed was formulated such that it was, in all respects except for the amendments noted, nutritionally the same as the industry standard feed. All the manure generated from each pen was collected less than one hour post-excretion. Each manure sample was immediately transported to a laboratory, where each sample was individually homogenized and a 25-gram aliquot of homogenized manure placed in separate flasks. The flasks were supplied with air via an air pump. The air passed across the manure and collected the ammonia emitted. The ammonia-laden air was then bubbled through individual acid solutions in separate flasks to capture the ammonia. Every 24 hours, for a period of 7 days, the acid solutions were changed with fresh solutions, and the solutions assayed to determine the amount of ammonia contained therein. The tabular data contained below represents the typical emission reductions noted for the feed formulations tested.

The resultant ammonia emissions are illustrated in Table 1. Over the period of 1 week, a 15% reduction in total ammonia emissions from manure derived from the acidogenic diet was noted. It is surmised that reactions of sulfate ions and ammonium ions to form ammonium sulfate may explain the reduction in overall ammonia emissions.

Experiment 2, Acidogenic/Zeolite Diet Effects on Manure Ammonia Emissions

In order to reduce the rise in ammonia emissions noted as the pH rises and ammonium deprotonates, a second material, clinoptilolite zeolite, was also added to the acidogenic feed. Zeolites as a group generally exhibit a high cation exchange capacity (CEC) and resistance to acid attack, and clinoptilolite zeolite exhibits a very strong preference for binding nitrogenous cations such as ammonium. Zeolites are known in the industry as a beneficial feed amendment for poultry, and will pass through the gut with their CEC and nitrogenous reactivity intact. A diet was tested where powdered clinoptilolite comprised 2% by weight of the diet, and gypsum was the source of 45% of the supplemental calcium added, with the standard diet previously indicated providing a baseline for comparative purposes. As can be seen in Table 1, the amended diet provided a significant (47%) reduction in ammonia emissions compared to the standard diet.

Experiment 3, Zeolite Diet Effects on Manure Ammonia Emissions

In order to determine whether the previously noted effect was due to zeolites alone, or was actually a synergistic effect between zeolites and acidogenic materials in feed, a non-acidogenic standard diet was reformulated so that powdered clinoptilolite would comprise 2% of the feed by weight. The previously indicated standard diet was used to form a baseline for comparative purposes. The result of feeding the zeolite-amended diet is noted in Table 1. The zeolite-amended diet emitted 13.4% more ammonia than the standard diet.

Experiment 4, Reduced Crude Protein/Acidogenic/Zeolite Diet Effects on Manure Ammonia Emissions

Additional reductions in ammonia emissions are obtainable by reducing fed CP levels such that excess indigestible or unusable proteins are minimized (Powers et al., 1998). The general thinking behind the strategy is that reductions in excess nitrogen in the feed will result in less nitrogen being excreted. A diet comprising powdered clinoptilolite at 2% by weight, gypsum providing 45% of the supplemental calcium in the diet, CP levels reduced by 3.8% compared to the standard diet used for comparison purposes (from 18.8% CP to 15.0% CP), and purified lysine added to the amended diet to meet the minimum nutritional needs of the hens was fed. A standard diet for that age bird containing 18.8% CP was used for comparison purposes. The results are presented in Table 1. Ammonia emissions were reduced by almost 77% compared to the standard diet.

Experiment 2-4, Zeolite-Amended Diet Effects on Total and Soluble Phosphorus Excretion

Bioavailable phosphate levels in all diets were similar. Manure from birds fed diets amended with the zeolite selected for use exhibited reduced soluble phosphorus levels due to the zeolite containing exchangeable calcium and magnesium cations. The cations reacted with soluble phosphates, forming insoluble compounds. Unexpectedly, excreted levels of total phosphorus were also reduced. The reductions in total and soluble phosphorus excretion were variable. Manure samples were collected to determine the level of reduced excretion for both forms of phosphorus. Standard laboratory methods were used for these determinations. Analytical data showing total and soluble phosphate levels in manure from amended and standard diets is presented in Table 3.

Experiment 5, Optimizing Dose Rates for Reduced CP/Acidogenic/Zeolite Dietary Amendment Levels

Dose optimization for the gypsum and zeolite blend resulted in even lower emission rates than initial studies indicated. A reformulated diet with 14.0% CP, where powdered clinoptilolite comprised between 0.75% and 1.25% by weight of the ration, and gypsum provided between 25% and 35% of the supplemental calcium in the diet was fed to birds. A standard diet comprising 14.3% CP (an appropriate dietary level for the age bird in this phase of the study) was fed as a control. The ammonia emission data is presented in Table 2. Ammonia emission reductions for optimized gypsum/zeolite amendment levels coupled with minor CP reductions ranged from 80% to 96%.

Experiment 6, Field test of Optimized Diet on High-Rise Layer House Ammonia Emissions

To test the effects of dietary modifications in the field, measurements of airborne ammonia were collected during the winter and summer in a high-rise layer house containing approximately 125,000 birds, where the birds were being fed the optimized reduced emissions diet comprising 1.25% zeolite, 35% of dietary Ca from gypsum, and 14.0% CP. A second house of the same size, population, and roughly the same age birds was used as a control, fed an industry-standard diet comprising 14.3% CP. During the winter, fans used to circulate air in the manure collection pit were not in operation, and in order to conserve heat, house ventilation via exhaust fan operation was reduced. During the summer, manure collection pit air circulation fans were in constant operation, and house ventilation via exhaust fan operation was increased to its maximum. Ten (10) fans in each house were selected as reference fans from which to obtain representative ammonia emission data. Analogous fans in each house were selected as the reference fans. A hand-held ammonia meter was set in front of each fan, allowed to equilibrate, and the values recorded. An average value for the house was calculated. Care was exercised so that when exhaust ammonia levels in the two houses were measured, the same number and type of fans were in operation. This was done to negate potential differences in terms of actual emission rates. Comparative data for this phase of the experiment is presented in Tables 4 and 5.

Conclusions

Feeding laying hens a diet containing clinoptilolite or other zeolites, and containing gypsum substituted for limestone such that less than 66% of the calcium added to the diet is derived from gypsum will significantly reduce manure ammonia emissions. Additional reductions in ammonia emission may be obtained by use of the optimized gypsum/zeolite amended diet coupled with CP reductions and purified amino acid supplementation early in the birds life-cycle when industry standard fed crude protein levels are highest. When the zeolite is pre-loaded with exchangeable phosphate-reactive materials, levels of excreted soluble phosphorus as well as total excreted phosphorus may be reduced.

Table 1

Experiments 1-4, Initial Testing of Reduced Emission Diets, Manure Ammonia Emission Levels Reported in ppm, Each experiment is averaged data from 4 pens containing 5 birds each, with 4 replicates.					
	Experiments 1-4 Control, data averaged from control for	Experiment 1 45% of Ca from Gypsum,	Experiment 2 45% of Ca from Gypsum 2% Zeolite 18.8% CP,	Experiment 3 2% Zeolite	Experiment 4 45% of Ca from Gypsum 2% Zeolite 15.0% CP
Day 1	288	69.5	42.8	144	0.99
Day 2	235	178	73	398	13.1
Day 3	57.9	142	90.6	107	50
Day 4	13.8	76.3	62	22.4	50
Day 5	4.9	26.9	30.4	6	17
Day 6	2.12	13.2	15.4	3.95	6.68
Day 7	1.67	6.59	4.4	2.81	2.8
Total	603.39	512.49	318.6	684.16	140.57
% Reduction	**0.00**	**15.06**	**47.20**	**-13.39**	**76.70**

Table 2

Experiment 5, Reduced Emission Diet Dose Optimization Study, Manure Ammonia Emission Levels Reported in ppm. Each data set is averaged data from 4 pens containing 5 birds each, with 4 replicates.			
	Control, 14.3% CP	25% of Ca from Gypsum 0.75% Zeolite 14.0% CP	35% of Ca from Gypsum 1.25% Zeolite 14.0% CP
Day 1	112	32.2	4.96
Day 2	185	31.6	0.79
Day 3	64.1	6.6	1.89
Day 4	7.96	1.55	2.36
Day 5	2.2	0.76	1.79
Day 6	1.56	1.15	1.87
Day 7	1.32	1.12	1.80
Totals	374.14	74.98	15.46
%Reduction	**0.00**	**79.96**	**95.87**

Table 3

Experiments 2-4, Effects of Dietary Zeolite on Manure Total/Soluble Phosphorus, Reported in lb P/ton of manure,		
	Average	Std. Dev.
Control Total P	13.5	2.6
Control Soluble P	4.2	2.2
Zeolite Total P	6.5	2.6
Zeolite Soluble P	1.6	0.8

Table 4

Experiment 6, Averaged Ammonia Emissions at Exhaust Fan Inlets in Winter, Reported in ppm.			
	35% of Ca from Gypsum 1.25% Zeolite 14.0% CP	Control 14.3% CP	% Reduction
1/16/2004	18.0	41.6	**56.7**
1/19/2004	17.2	45.5	**62.2**
1/20/2004	15.7	40.0	**60.8**
1/21/2004	15.0	43.1	**65.2**
1/22/2004	14.8	35.0	**57.7**
1/23/2004	14.5	36.4	**60.2**
1/29/2004	18.0	39.6	**54.5**
1/30/2004	16.9	37.0	**54.3**
2/03/2004	11.5	42.7	**73.1**
2/04/2004	12.8	45.4	**71.8**
2/05/2004	12.0	48.8	**75.4**
2/09/2004	12.0	53.0	**77.4**
2/10/2004	8.6	48.8	**82.4**
2/16/2004	8.3	43.3	**80.8**
2/18/2004	5.9	41.1	**85.6**

Table 5

Experiment 6, Averaged Ammonia Emissions at Exhaust Fan Inlets in Summer, Reported in ppm.			
	35% of Ca from Gypsum 1.25% Zeolite 14.0% CP	Control 14.3% CP	% Reduction
4/16/2004	36.7	100	**63.3**
4/19/2004	43.4	68.8	**36.9**
4/20/2004	37.7	56.1	**32.8**
4/21/2004	34.8	57.3	**39.3**
4/26/2004	27.6	50	**44.8**
4/28/2004	12.1	30.7	**60.6**
4/30/2004	30.6	42	**27.1**
5/03/2004	23.1	36.1	**36.0**
5/07/2004	22.5	40.9	**45.0**
5/10/2004	21.4	45.9	**53.4**
5/11/2004	16.2	27.9	**41.9**
5/17/2004	21.1	38.9	**45.8**

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