Effects of Aluminum Sulfate and Aluminum Chloride Applications to Manure on Ammonia Emission from a High-Rise Layer Barn

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Species:	Poultry (Layer)
Use Area:	Animal Housing
Technology Category:	Chemical Amendment
Air Mitigated Pollutants:	Ammonia

Description:

High concentrations and emission rates of ammonia (NH_3) are a major air quality concern for modern and large layer facilities. However, very few studies have been conducted to systematically quantify NH_3 emission from such facilities, while even fewer have reported the effects of whole-barn emission mitigation strategies. Practices to reduce NH_3 emission include diet manipulation, manure drying, frequent manure removal, and manure amendment.

The effectiveness of aluminum sulfate (alum, $Al_2(SO_4)_3$) as a litter amendment in broiler houses has been proven in both lab-scale experiments (Moore et al., 1995) and field tests (Armstrong et al., 2003; Worley et al., 1999). The addition of alum to poultry litter reduces NH_3 volatilization; increases total and soluble N in the litter, which in turn increases N/P ratios; reduce fuel (heating) costs; and lowers in-house NH_3 concentrations. Alum application also potentially improves bird health and reduces phosphorous runoff. However, there have been no studies of alum and aluminum chloride ($AlCl_3$) applications in commercial size, high-rise layer barns. There are significant differences between layer and broiler houses. The major differences are that in high-rise houses: 1) manure is stored without litter, 2) the manure is stored on the first floor out of reach of the birds, 3) a significant amount of fresh manure does not reach the manure storage for several hours, and 4) manure is stored for much longer periods. Therefore, a full-scale test in a layer barn was needed to study the effectiveness of alum and $AlCl_3$ in reducing ammonia emissions.

Mitigation Mechanism:

Large amounts of manure are stored in the first floor of high-rise layer barns for up to one year. Ammonia emissions from these barns can therefore be significant, and are affected by factors such as manure management, manure drying strategies, diet, and geographical location. Nutrients are released from manure by microbial processes into forms that can be taken up by plants or emit into the environment. Nitrogen is released as ammonium (NH_4+) under acidic or neutral conditions, or as NH_3 at higher pH levels. Applying acidifying agents to reduce manure pH values can be an effective method to reduce NH_3 volatilization. Alum was identified as an economical agent to reduce NH_3 volatilization and the amount of soluble phosphorous in the manure (Moore et al., 1995).

Applicability:

Either dry or liquid alum can be used to amend manure pH, but the additional water associated with liquid alum can increase manure moisture content, which tends to increase ammonia release. Ammonia concentration and emission rate in layer barns is much larger if the manure moisture content is not minimized. Alum application between growth cycles when broiler houses are empty was proven effective in reducing broiler house NH_3 emissions (Worley et al., 2000). Alum applications in high-rise layer barns are much less convenient and there are several reasons the same success of alum in broiler houses may not be realized in layer houses. Layer manure is: 1) not mixed with litter, 2) stored in large piles on the first floor, 3) sometimes on the second floor for several hours before being scraped into the first floor, 4) stored in the barn for 4 to 8 times longer than broiler manure. Because of the existing untreated pile of manure at the beginning of the test, dry alum was manually applied initially, and an automated spraying system was used to regularly apply liquid alum in the treated barn.

The ammonia mitigation tests were conducted at two 169,000-hen capacity high-rise layer barns in Ohio. The tests were conducted to evaluate baseline and mitigated emission rates. The test was conducted at the site of a six-month particulate impaction system test (Lim et al., 2005). A spraying system for applying alum and $AlCl_3$ was installed in the treated Barn 2. Concentrations were measured at the barn exhaust fans and in incoming air, using well-maintained and -calibrated online ammonia analyzers. Other measured variables included temperatures, relative humidity, building static pressure, and fan operation.

The mean untreated NH_3 emission rate was 480 g/d-AU (1.35 g/d-hen), where AU is an animal unit or 500 kg (1100 lb) of bird weight. The alum and $AlCl_3$ applications reduced NH_3 emission by 23%, based on the NH_3 emission differences between barns, Figure 1. Mitigation efficiency of the alum application was compromised by clogged nozzles, manure turning, and the introduction of a new flock of hens. Higher reductions of 33, 23 and 40% were achieved during later test periods. The application of $AlCl_3$ in the last test was expected to further reduce NH_3 emission, but the reduction was only 27%, which was probably due to the higher moisture content of manure in Barn 2.

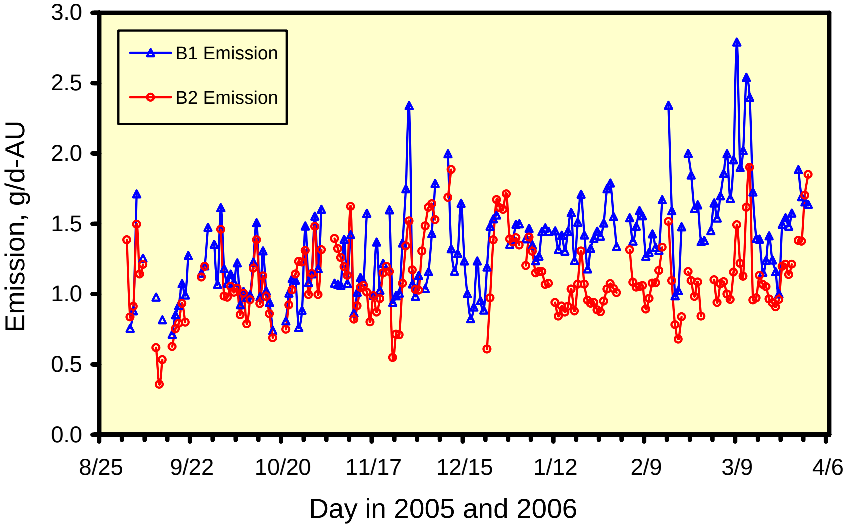

Figure 1. Daily mean NH_3 emissions of untreated Barn 1 and treated Barn 2.

Limitations:

Application of dry alum was not economically feasible because of higher costs. Results indicated that since manure moisture content (in percentage) ranged from the upper 20s (warm months) to the upper 30s (cold months), the amount of liquid alum that can be applied is limited. The additional chemical solution from frequent spraying and flushing the system with water had increased manure moisture content, especially in cold weather, thus reducing mitigating effectiveness.

The nozzles were easily clogged by alum salt accumulation, thus requiring frequent maintenance and cleaning. The automated spraying system required training to operate and maintain. Furthermore, the chemicals were acidic and corrosive, making it more difficult to check for spraying efficiency during system operation. The spraying area was also limited to avoid damaging the manure drying fans in the pit, and was not applied in the area along the side walls where barn ventilation fans were located.

The major limitation is related to the fact that manure that is on the second floor is not treated. Since NH_3 release from manure decreases exponentially after excretion, the second floor manure emits more NH_3. Previous studies have shown that approximately 50% of a high rise barn's ammonia emissions are from the second floor and 50% are from the first floor. Therefore, the theoretical limit of the potential reduction of alum application to the first floor is only 50%.

Cost:

The costs of the alum and $AlCl_3$ were $0.13/L and $0.14/L, respectively, without delivery charges. At each delivery, 5678 L (1500 gal) of alum or $AlCl_3$ was first added into the holding tank, and an equal volume of water was added to produce a 50% solution. The field records showed that five deliveries worth $3700 of alum were used in 85 days, or $44 per barn per day. The automatic spray controller cost about $3000, and the doubled-wall holding tank was $6500. A single wall tank would be less expensive. The labor to maintain the controller, air and water pumps is estimated at 3 hours per week per barn. The air pump provided the pressure for spraying, and the water pump filled the spray pipe with the solution.

Implementation:

Several tests were conducted during the seven month alum and $AlCl_3$ test. The tests were conducted in conjunction with tests of the Electrostatic Space Charge System (ESCS) (Lim et al., 2008). Both the ESCS and alum tests were conducted in B2, while B1 served as the untreated (control) barn. The test schedule and descriptions are listed in Table 1. A total of six tons of dry alum were manually sprayed onto the manure surfaces before the alum solution spraying was started. The application of dry alum was about 1.4 kg/m² of manure surface. An 11,360-L (3000-gal) holding tank was used to store the chemicals, while spray tubes and sprinkling nozzles were installed along the barn length. Solutions were sprayed for four seconds every hour. .The Alum spraying system and ESCS operated simultaneously between September 29, 2005 and January 20, 2006 (Test 4).

Table 1. Tests conducted during study.

Test	Date	Description	Emission difference
1	9/1-9/10	ESCS	11%
2	9/11-9/20	Alum	29%
3	9/21-9/29	ESCS	12%
4a	9/30-11/4	ESCS + alum, some nozzles were clogged	16%
4b	11/5-12/12	ESCS + alum, nozzles were cleaned on 11/4	16%
4c	12/22-1/20	ESCS + alum, new hens in B2, nozzles cleaned (1/12)	17%
5	1/21-2/9	ESCS + alum (A7, single dose)	33%
6	2/10-2/15	ESCS + alum (A7, 1.5 dose)	23%
7	2/16-3/7	Alum (A7, 1.5 dose) + evening manure scraping*	40%
8	3/8-3/31	Aluminum chloride + evening manure scraping	27%

* ESCS operation was discontinued on March 4, 2006.

Many nozzles were clogged by alum salt accumulation during Test 4, and had to be removed and cleaned. Other maintenance included replacing the alum spraying pump and flushing nozzles with water to prevent clogging. Barn 2 was emptied on December 13, and was restocked with new birds on December 17. The original alum was replaced with a new formula ("A7") on January 21 (Test 5). Application rate was increased by increasing the spray time for Test 6. The manure scraping schedule was changed from morning to evening for Test 7, to reduce the amount of time that manure produced during the day was left untreated on the second floor. Aluminum chloride was applied in Test 8. It was assumed that the ESCS did not significantly affect the abatement efficacy of alum and AlCl3 on NH3 emissions.

The mean NH3 emission rates were 403 and 365 g/d-AU for B1 and B2, respectively, before the alum spraying was started. The overall average emission rates during the alum tests (Tests 2 and 4 to 8) were 483 g/d-AU for B1 (control) and 369 g/d-AU for B2. The Test 3 emission rates were excluded in the comparison because it was assumed that the residual alum from Test 2 continued treating the manure during Test 3 after the Alum application was discontinued.

The overall paired emission differences between the two barns were 11% and 23% for the control test period (Test 1) and the experiments (Tests 2 and 4 to 8), respectively. Since the B2 NH3 emission rate of Test 1 was 11% (mean of 4 paired emission rate differences) lower than B1, the overall reduction of 23% due to alum and AlCl3 applications may be slightly lower. However, the 11% difference in Test 1 was calculated from a small number of paired emission values, and lasted only 10 days in September, which is a very small portion of the seven-month test, thus the barn difference before the treatment was not used to correct or adjust the reductions in subsequent tests.

The mean NH3 emission rates of Test 2, when the dry and alum solution was first applied, were 321 and 213 g/d-AU for B1 and B2, respectively. It was apparent that the B2 NH3 emission rate was reduced by alum application as the mean paired B2-B1 emission reduction was 29% (n=7 out of 10 d). In Test 4, the ADM NH3 emission rates were 447 and 379 g/d-AU for B1 and B2, and the mean paired difference was 16% (n=31 d, September 30, 2005 to January 20, 2006). The lower NH3 emission reduction in Test 4 was probably due to the clogged nozzles, manure turning activities, and the lack of a layer of alum as compared with Test 2. The clogged nozzles reduced the alum application rate and the total area of alum-treated manure surfaces, thus lowering the emission reduction. The more frequent manure turning may have destroyed the protective layer of alum. This is especially true when a significant part of the NH3 emission was expected to be generated by the newly scraped, fresh manure on the surfaces of the piles. The lower reduction at the end of December (Test 4c) was probably caused by the new flock of hens in B2, in addition to the many clogged nozzles. After the flock adapted to the new environment, and more than 40 nozzles were removed and cleaned, the paired NH3 emission differences averaged 35% (n=8) for January 13 to 20, 2006.

The mean NH3 emission reductions were 33%, 23%, 40%, and 27% for Tests 5 to 8, respectively. The highest paired NH3 emission reductions were observed in Tests 5 and 7, which were probably due to the combined effects of well-functioning nozzles, evening manure scraping, and application of the A7 alum. Due to the lack of test replication and only one treated barn, it is not known which factor contributed the most. The emission rate differences between the two barns averaged 32%, and ranged from -10% to 52% between January 21 and March 31.

The mean NH3 emission rates were 583 and 415 g/d-AU for B1 and B2 in the test of AlCl3 (Test 8). The abatement effect of AlCl3 appeared to be lower than alum, but the lower reductions were probably caused by the higher manure moisture content in B2. Manure in B2 was observed to be wetter at the end of the tests, most likely due to the amount of moisture from increased spraying rate and additional flushing water from cleaning the spraying system. Manure with higher moisture content was expected to release more NH3 than drier manure piles. The other important factor was the lower barn ventilation rate in the colder months. The mean barn airflow rates were 242, 57, and 81 m^3/s during Tests 2, 7 and 8, respectively. Since barn airflow was over 70% lower in the colder months, the extra moisture applied onto the manure surfaces was probably not removed as efficiently in the warmer months. Manure moisture content and pH values are reported in Figure 2.

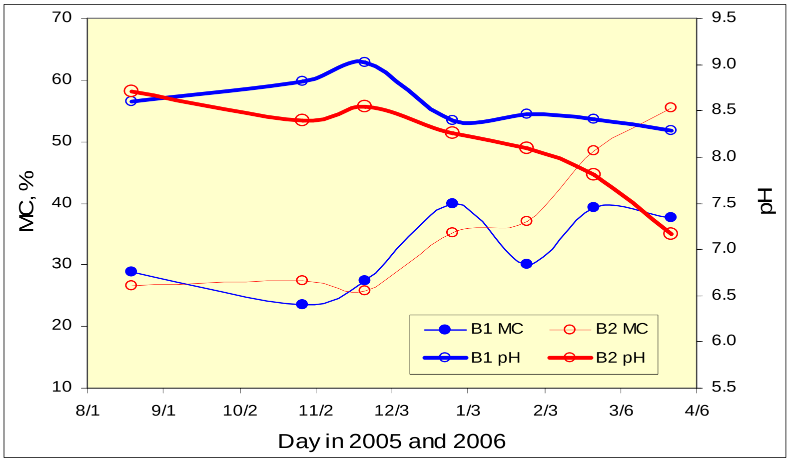

Figure 2. Mean manure moisture content and pH values of untreated Barn 1 and treated Barn 2.

Technology Summary:

Dry alum, and liquid alum and $AlCl_3$ solutions were applied in a high-rise layer barn to reduce NH_3 emission. Dry alum was manually applied at the beginning of the test, while the solutions were automatically sprayed every hour. The alum application reduced NH_3 emission rate by 29% when dry and liquid alum were first applied. The alum and $AlCl_3$ applications reduced NH_3 emission by 23%, based on the overall cross-barn comparison of paired NH_3 emission rates.

The NH_3 mitigation efficiency of the alum application was compromised by clogged nozzles, manure turning, and introduction of a new flock of hens. Higher reductions of 33%, 23%, and 40% were achieved in Tests 5 to 7. The efficacy of the alum spraying was the highest from January 21 to March 7, 2006, when the nozzles were well maintained, manure turning was discontinued, application rate was increased, and daily manure scraping was switched from morning to evening. The paired emission rate differences between the two barns averaged 32%. The application of $AlCl_3$ was expected to further reduce NH_3 emission, but averaged only 27% in Test 8, which was probably due to higher moisture content of manure in B2.

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