Reduction of Ammonia Emissions from Stored Laying Hen Manure Through Topical Application of Zeolite, Al$^+$Clear, Ferix-3, or Poultry Litter Treatment

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Primary Audience: Agricultural Engineers, Poultry Managers, Researchers

SUMMARY

Practical means to decrease aerial emissions will enhance the ability of the US egg industry to improve environmental stewardship while continuing to provide consumers safe and affordable eggs. Ammonia emissions from manure-belt laying hen houses have been shown to be less than 10% of the emissions from high-rise counterparts where manure is stored in-house for a year. However, on-farm manure storage for manure-belt houses also emits NH_3, which is a part of the total farm emissions. Nevertheless, treating manure in storage sheds to decrease NH_3 emissions may be more readily implemented than treatment inside the layer houses because of potential bird health concerns and possible detrimental effects of the treatment on the housing equipment. The laboratory-scale experiments reported here examined the efficacy of 4 commercially available treatment agents, topically applied to laying hen manure at 3 different dosages, in decreasing NH_3 emissions from the manure storage. The treatment agents included zeolite, 2 forms of Al$^+$Clear (aluminum sulfate, 48.5% liquid and granular), Ferix-3 (ferric sulfate), and Poultry Litter Treatment (PLT, sodium bisulfate). All the tested agents showed appreciable NH_3 emission reduction of 33 to 94%. In all cases, the greatest application dosage provided little additional NH_3 reduction as compared with the medium dosage ($P > 0.70$). Comparison among the dry granular Al$^+$Clear, Ferix-3, and PLT in reduction of NH_3 emission over a 7-d manure storage period showed no significant difference when the agents were applied at 0.5 kg/m^2 of manure surface area ($P = 0.40$) but greater reduction for Al$^+$Clear (92 ± 3%) and Ferix-3 (90 ± 1%) as compared with PLT (81 ± 2%) when applied at 1.0 kg/m^2 ($P < 0.01$). Further field verification tests of the laboratory-scale findings are warranted.

Key words: ammonia emission, laying hen, mitigation, manure treatment agent

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DESCRIPTION OF PROBLEM

Ammonia emissions from animal feeding operations not only decrease the fertilizer N value of the manure but also lead to environmental pollution. Hence, cost-effective means to decrease NH_3 loss associated with animal housing, manure storage, and land application will have positive economic and environmental effects.

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Laying hen manure is typically either accumulated in the lower level of high-rise houses or frequently removed from manure-belt (**MB**) houses to designated storage facilities. Various mechanisms may be involved in conserving N constituted in poultry manure during storage, such as immobilization of NH_4^+ through addition of easily decomposable, N-poor materials, adsorption of NH_4^+ and NH_3 onto amendments, and regulation of manure pH [1, 2].

Natural zeolite $[(Na_4K_4)(Al_8Si_{40})O_{96}\cdot 24H_2O]$ is a cation-exchange compound that has high affinity and selectivity for NH_4^+ ions because of its crystalline, hydrated properties resulting from its infinite, 3-dimentional structures [3]. It has been used as an amendment to poultry litter [4, 5], in anaerobic digesters treating cattle manure [6], in composting of pig slurry and poultry manure [7, 8], as an air scrubber packing material to improve poultry house environment [9], and as a filtration agent in deep-bedded cattle housing [10]. Specific research findings include trapping of >90% of N loss during 13-d composting of pig slurry by placing 12% (by weight) zeolite and chopped straw mixture in the air stream [7], 44% reduction in NH_3 loss during 56-d composting of poultry manure with a surface application of 38% (by weight) zeolite [8], and 22 to 47% reduction in NH_3 emissions over 4-d storage of slurry dairy manure when mixed with 2.5 to 6.25% (by weight) zeolite [10]. The kinetics of NH_4^+ adsorption and desorption by zeolite at various pH and initial NH_4^+ concentrations have been investigated as well [11].

Ammonia volatilization stems from microbial decomposition of nitrogenous compounds, principally uric acid, in poultry manure. Manure pH plays a key role in NH_3 volatilization in that NH_3 generation tends to increase with pH. Uric acid decomposition is most favored under alkaline (pH > 7) conditions, and the effect of uricase, the enzyme that catalyzes uric acid breakdown, reaches maximum at pH of 9. Consequently, NH_3 emissions can be inhibited by acidulants that lower manure pH and decrease conversion of NH_4^+ to NH_3. The acidulants also inhibit bacterial and enzyme activities that are involved in the formation of NH_3, thus decreasing NH_3 production. Liquid Al$^+$Clear (48.5%) [12] and dry granular Al$^+$Clear (aluminum sulfate) [12], Ferix-3 (ferric sulfate) [13], and Poultry Litter Treatment (**PLT**; sodium bisulfate) [14] are acidulants that, when hydrated, produce hydrogen ions (H^+) that attach to NH_3 to form NH_4^+. As a result of the reaction, the amount of NH_3 emitting from the manure is decreased, thereby preserving the N content of the manure. Al$^+$Clear and PLT have been applied to poultry litter to control NH_3 volatilization [8–11, 15–18]. Ferix-3 usually is used for industrial and municipal water and wastewater treatment over a wide pH range for color, organics, phosphorous, heavy metal, arsenic and bacteria removal, turbidity, chemical oxygen demand, or biological oxygen demand reduction and enhanced coagulation. Ferix-3 performs well in soil remediation applications. However, information on the efficacies of the 3 acidulants on NH_3 mitigation with laying hen manure is meager.

The objectives of this laboratory-scale study were 2-fold: a) to quantify the efficacies of zeolite, liquid Al$^+$Clear, granular Al$^+$Clear, granular Ferix-3, and PLT topically applied at different rates onto laying hen manure on reduction of NH_3 emissions from the manure storage, and b) to compare NH_3-reduction efficiency among Al$^+$Clear, granular Ferix-3, and PLT topically applied at 2 dosages.

MATERIALS AND METHODS

Air Emission Vessels

Eight emission vessels were built and used in the study (Figure 1). They were placed in an environmentally controlled room that was kept at a constant temperature of 23°C (73°F). The vessels were made of 19-L (5-gal) plastic containers. To prevent potential interference of the vessel interior (polyvinyl chloride) surface with NH_3 emission measurement, the vessels were lined with Teflon FEP100 film (200A) [19]. Both the air inlet and outlet were located in the airtight lid. Teflon tubing (0.635-cm or 0.25-in. diameter) was used in the emission vessel system. The vessels were operated under positive pressure. A diaphragm pump (model DOA-P104-AA) [20] was used to supply fresh air to the emission vessels. Flow rate of the fresh supply air was controlled and measured with an air mass flow controller [0 to 30 liters per minute (LPM), with stainless steel wetted parts] [21]. The supply air was connected to a distribution manifold, where air was further divided via 8 identical flowmeters (0.2 to 4 LPM, stainless steel valve, VFB-65-SSV) [22]. A flow rate of 3 LPM was introduced into each vessel, resulting in an air exchange rate of 11 air changes/h. Each vessel was equipped with a small stirring fan (12VDC) [23] located 6.4 cm (2.5 in.) below the lid for uniform mixing of the headspace. Gas exhausted from the vessels was connected to a common 5-cm (2-in.) polyvinyl chloride pipe that was routed to the building vent outlet.

Samples of the exhaust air from each of the 8 vessels, the supply air, and the room air were successively taken and analyzed at 6-min intervals, with the first 4 min for stabilization and the last 2 min for measurement. This yielded a measurement cycle of 1 h for each vessel. The successive sampling was achieved by controlled operation of solenoid valves (type 6014, 24 V, stainless steel valve body) [24]. A Teflon filter was placed in front of each solenoid valve. The NH_3 concentrations were measured with a photoacoustic infrared NH_3 analyzer (Chillgard RT Refrigerant Monitor) [25] that uses an internal pump to draw sample air at a flow rate of approximately 1.0 LPM. The NH_3 analyzer was checked weekly and calibrated, as appropriate, with Environmental Protection Agency-certified calibration gases. Manure temperature was measured with type T thermocouples (0.2°C or 0.36°F resolution). Air temperature and RH of the room were monitored with a temperature-RH data logger (HOBO Pro RH/Temp) [26]. Analog outputs from the thermocouples, the NH_3 analyzer, and the mass flow meter were logged at 20-s intervals into a measurement and control unit (CR10) [27].

Figure 1. Emission vessel system used to evaluate the efficacy of various manure treatment agents to decrease ammonia emissions from manure storage.

Laying Hen Manure and Mitigation Options Tested

Nearly fresh (<1 d old) laying hen manure collected on a manure belt in a commercial MB layer house was used in this research. For each trial, a new batch of manure was procured and mixed before it was randomly assigned to 8 emission vessels. Manure samples with an initial weight of 2.5 kg (5.5 lb) were used as the experimental units. The 2.5-kg sample was placed either in a 3.8-L (1-gal) container (surface area of 0.02 m^2 or 0.22 ft^2) that was further placed inside the 19-L (5-gal) emission vessel or directly placed in the emission vessel (surface area of 0.05 m^2 or 0.54 ft^2). Five treatment additives at various application rates were evaluated, including natural zeolite, 2 forms of Al^+Clear (48.5% liquid and dry granular), Ferix-3, and PLT (see Table 1 for properties of the chemical additives). Two experiments with the additives were conducted to address the proposed study objectives: a) quantifying the effects of topical application rate of each additive on reduction of NH_3 emission from hen manure storage and b) comparing NH_3 emission reduction efficacy among 3 granular chemical additives, Al^+Clear, Ferix-3, and PLT.

In the experiment that quantified the effect of additive application rate, separate tests were run for each additive. Specifically, the application rates were 2.5, 5, or 10% of the manure weight (3.1, 6.3, or 12.5 kg/m^2 of manure surface area or 0.63, 1.29, or 2.55 lb/ft^2) for zeolite; 1, 2, or 4 kg/m^2 (0.20, 0.41, or 0.82 lb/ft^2) for liquid Al^+Clear; and 0.5, 1.0, or 1.5 kg/m^2 (0.10, 0.20, or 0.30 lb/ft^2) for granular Al^+Clear, Ferix-3, and PLT. Selection of the application rates was

Table 1. Physical and chemical properties of Al+Clear, Ferix-3, and Poultry Litter Treatment (PLT)[1]

Item	Liquid Al+Clear	Dry Al+Clear	Ferix-3	PLT
Molecular formula	$Al_2(SO_4)_3{\cdot}14H_2O$	$Al_2(SO_4)_3{\cdot}14H_2O$	$Fe_2(SO_4)_3{\cdot}9H_2O$	$NaHSO_4$
Molecular weight	594	594	562	120
pH	2.0 (approximately)	3.5 (1% solution)	1.02 (10% solution)	<1 (5% solution)
Appearance	Clear	White granules	Yellowish granules	Off-white granules
Physical state	48.5% in water	Dry solid	Dry solid	Dry solid
Odor	Odorless	Odorless	Slight	Odorless

[1][12–14].

to cover the range of low to high dosages, as compared with the published commercial application rates for broiler litters. Two vessels were used as control (Ctrl; i.e., no application of additive). Two or 3 trials were conducted to obtain 4 or 6 replicates of each treatment. The trials of the 4 chemical additives each lasted 7 d. In the case of zeolite treatment, 3 trials were conducted, with the first 2 trials examining the effects of single application at the previously stated 3 application rates over a 14-d storage period and the third trial examining the effect of multiple applications at the 5% weight application rate every 2 d over a 14-d test period. Specifically, for the third trial, an equal amount of fresh manure (2.5 kg per layer of 5 cm or 2 in.) was added to all vessels every other day for 4 layers, simulating manure removal from MB hen houses into manure storage. Zeolite of 125 g (5% by weight) was topically applied to each layer in 4 vessels, whereas the other 4 vessels served as Ctrl. The manure was loaded directly into the 19-L (5-gal) emission vessel with 0.05 m^2 (0.54 ft^2) manure surface area, resulting in a zeolite application rate of 2.55 kg/m^2 manure surface (0.52 lb/ft^2). The results from a related study had indicated that the surface layer manure [2.5 to 5 cm (1 to 2 in.) of the top layer] seemed to be the main contributor to NH_3 loss in laying hen manure storage [28]. Therefore, manure samples were taken from the top 2.5 cm (1 in.) at the end of the trial period, and their physical and chemical properties were analyzed by a certified commercial analytical laboratory.

In the experiment comparing the efficacies among the chemical additives of Al+Clear, Ferix-3, and PLT, the 3 additives were applied at 2 dosages (0.5 and 1.0 kg/m^2 or 0.10 and 0.20 lb/ft^2), leading to 6 additive regimens plus Ctrl. The 6 additive regimens along with the Ctrl were randomly assigned to 8 emission vessels containing the same batch of hen manure, 1 vessel per regimen plus 2 vessels for Ctrl. Use of the same batch of hen manure for the different additives was to eliminate the potential effect of temporal nonhomogeneity in the manure on NH_3 reduction efficacy by the additives. Three trials, each lasting 7 d, were conducted to yield 3 replicates for each additive regimen and 6 replicates for the Ctrl.

Data Analysis

From the hourly air flow rate and NH_3 concentration data, the corresponding NH_3 emission rate of the manure (g/h per kg or g/h per m^2) was calculated for each vessel. Summation of 24 hourly NH_3 emission values yielded the daily NH_3 emission (g/d per kg or g/d per m^2). Statistical analyses of the daily NH_3 emissions were performed using the GLM of SAS for least squares means [29]. The statistical analyses were conducted to evaluate the effects of application rates of each additive on NH_3 emission and to compare the efficacy of NH_3 emission reduction among the additives of Al+Clear, Ferix-3, and PLT at 2 application rates (0.5 and 1.0 kg/m^2, 0.10 and 0.20 lb/ft^2). Differences in all comparisons were considered significant at $P < 0.05$.

RESULTS AND DISCUSSION

Effect of Zeolite on Hen Manure NH_3 Emission

Topical application of zeolite on fresh hen manure substantially decreased NH_3 emission during the 14-d storage period, and the magnitude of emission reduction was generally proportional to application rate. Daily NH_3 emissions from manure with single application of

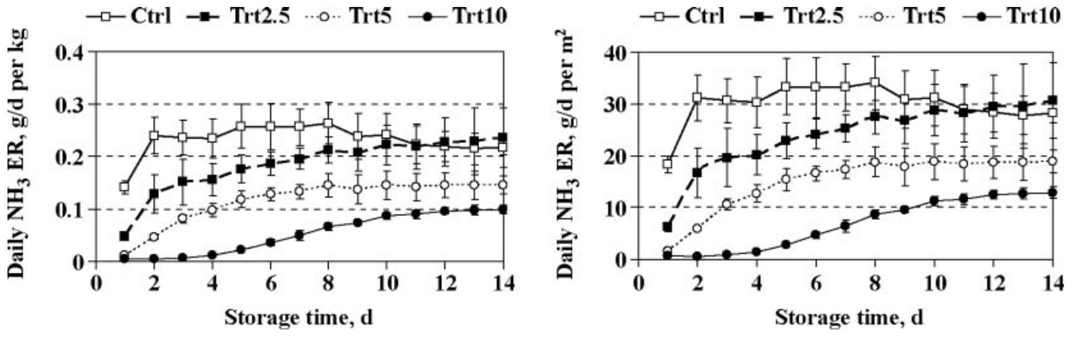

Figure 2. Daily ammonia emissions (mean and SE, n = 4) of ventilated laying hen manure storage with various rates of single topical application of zeolite (Ctrl = no zeolite; Trt2.5 = 2.5% zeolite by weight or 3.1 kg/m^2; Trt5 = zeolite 5% by weight or 6.3 kg/m^2; Trt10 = 10% zeolite by weight or 12.5 kg/m^2). ER = emission rate.

zeolite are shown in Figure 2. The adsorption of NH_3/NH_4^+ took effect right after the application and had the largest emission reduction on d 1. Ammonia emission rates were 18.3, 6.15, 1.61, and 0.73 g/d per m^2 at the end of d 1 for the application rate of 0 (Ctrl), 2.5, 5, and 10%, respectively—a NH_3 emission reduction of 66, 91, and 96%, respectively. Ammonia emission from the Ctrl vessels stabilized after 3 d, whereas emissions of the treatment (Trt) vessels continued to incline, with Trt2.5 being most obvious. Daily NH_3 emission rates of Trt5 and Trt10 were significantly lower than that of Ctrl ($P < 0.01$) throughout the 14-d test period. However, significant difference between Trt2.5 and Ctrl was observed only during the first 7 d ($P < 0.01$; $P = 0.65$ after d 7).

For multiple manure additions and zeolite applications (every 2 d), the zeolite (Trt5) was shown to significantly lower NH_3 emission during the 14-d trial ($P < 0.01$), ranging from 73.2 to 20.2%. Addition of 2 or more layers of manure did not increase NH_3 emission on a per-vessel basis (g/d per vessel or g/d per m^2), largely because of the unchanged emitting surface area in the vessel (Figure 3). However, on a per unit of manure mass or weight basis (g/d per kg), daily emission rate decreased progressively with the addition of manure ($P < 0.01$).

Table 2 summarizes the effects of single or multiple topical applications of zeolite at the 3 dosages. For the single applications, the cumulative NH_3 emission reductions over 7- and 14-d periods were, respectively, 36 and 20% for Trt2.5 (2.5% weight or 3.13 kg/m^2), 62 and 50% for Trt5 (5% weight or 6.25 kg/m^2), and 92 and 77% for Trt10 (10% weight or 12.5 kg/m^2). The cumulative reduction of multiple applications over a 7-d period after the last application was 33% for Trt5 (5% weight or 2.55 kg/m^2), which was slightly lower than the reduction rate by the Trt2.5 single application. The difference arose

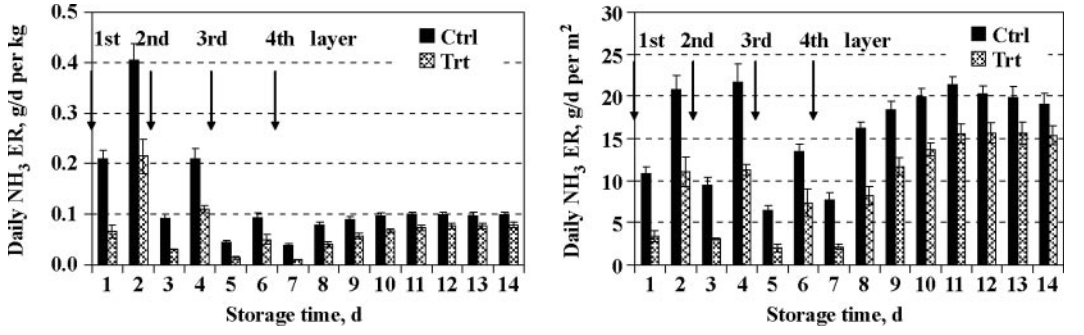

Figure 3. Daily ammonia emissions (mean and SE, n = 4) of ventilated laying hen manure storage. Fresh manure was added on d 0, 2, 4, and 6, and zeolite was topically applied subsequently in treatment vessels (Ctrl = no zeolite; Trt = 5% zeolite by weight or 2.55 kg/m^2). ER = emission rate.

from the lower application rate of Trt5 vs. Trt2.5 on the basis of application per unit area (2.55 vs. 3.13 kg/m^2).

Effects of Al^+Clear, Ferix-3, and PLT Treatment on Hen Manure NH_3 Emission

Topical application of Al^+Clear (liquid and granular), Ferix-3, and PLT on fresh hen manure also considerably decreased NH_3 emissions during a 7-d storage. Daily NH_3 emissions from the Trt and Ctrl regimens are illustrated in Figure 4. Results on NH_3 emissions for each regimen, emission reduction by Trt with reference to Ctrl, and manure properties at the end of a 7-d storage are summarized in Table 3. The different batches of manure involved throughout the tests had different pH values (7.0 to 7.5) and NH_3 emissions (58.8 to 148 g/m^2 over a 7-d storage period) for the Ctrl regimen. As a result, direct comparisons in emission reduction among the additives could not be made in the first experiment. Instead, only NH_3 emissions and emission reduction rates for a given additive over the 7-d test period were compared to delineate the effects of different application dosages (objective 1). The reductions of NH_3 emissions relative to the Ctrl were: A) 63, 89, or 94%, respectively, for liquid Al^+Clear applied at 1, 2, or 4 kg/m^2 manure surface area; B) 81, 93, or 94%, respectively, for granular Al^+Clear applied at 0.5, 1.0, or 1.5 kg/m^2; C) 82, 86, or 87%, respectively, for Ferix-3 applied at 0.5, 1.0, or 1.5 kg/m^2; and D) 74, 90, or 92%, respectively, for PLT applied at 0.5, 1.0, or 1.5 kg/m^2. Clearly, in each case, the greatest dosage provided little additional emission reduction, as compared with the medium dosage ($P > 0.70$). Ammonia emissions for all 3 dosages were significantly lower than that for the Ctrl ($P < 0.001$). By the end of 7-d test period, NH_3 emission reduction for the least dosage was less than that for the 2 greater dosages ($P < 0.001$).

Daily NH_3 emission of the Ctrl vessels became relatively stabilized after d 3 (Figure 4). Ammonia emissions for the lowest application rate started to increase on d 3, 5, 6, and 7 for liquid Al^+Clear, PLT, granular Al^+Clear, and Ferix-3, respectively.

The manure properties indicate that greater application rates of the additives led to lesser pH, lesser total ammoniacal N (**TAN**) content, and greater total N content in the top 2.5 cm (1 in.) layer of the manure after a 7-d storage (Ta-

Table 2. Effects of topical application of zeolite at various rates on reduction of ammonia emission from laying hen manure storage[1]

	Single application (in 1-gal emission vessels)				4 layers (5-gal vessels)	
Variable	Ctrl	Trt2.5	Trt5	Trt10	Ctrl	Trt5
Amount of manure, kg	2.5	2.5	2.5	2.5	10	10
Surface area of manure, m^2	0.02	0.02	0.02	0.02	0.05	0.05
Number of zeolite application	1	1	1	1	4	4
Trial-treatment duration, d	14	14	14	14	14	14
Application rate, kg/m^2	0	3.125	6.25	12.5	0	2.55
Average daily emission rate per unit of manure weight, g/kg per d	0.231	0.185	0.116	0.053	0.125	0.069
7-d cumulative emission, g/kg	1.6[a]	1.0[b]	0.62[c]	0.14[d]	—	—
7-d emission reduction,[2] %	—	36[c]	62[b]	92[a]	—	33[3]
Total cumulative emission,[4] g/kg	3.0	2.5	1.4	0.7	1.7	1.0
Total cumulative emission reduction, %	—	20	50	77	—	44
8-d emission reduction,[5] %	—	—	—	—	—	54

[a–d]Means in a row not having a common superscript are significantly different ($P < 0.05$).

[1]The application rates, expressed in percentage of manure weight, were 0% (Ctrl), 2.5% (Trt2.5), 5% (Trt5), and 10% (Trt10), respectively.

[2]Calculated as: $$\text{Emission reduction rate }(\%) = \frac{\text{CumulativeEmission}_{\text{Control}} - \text{CumulativeEmission}_{\text{Treatment}}}{\text{CumulativeEmission}_{\text{Control}}} \times 100.$$

[3]Cumulative emission reduction over 7-d after the last-layer addition of hen manure.

[4]Comparison tests lasted 14 d.

[5]Represents cumulative emission reduction during first 8 d of manure additions.

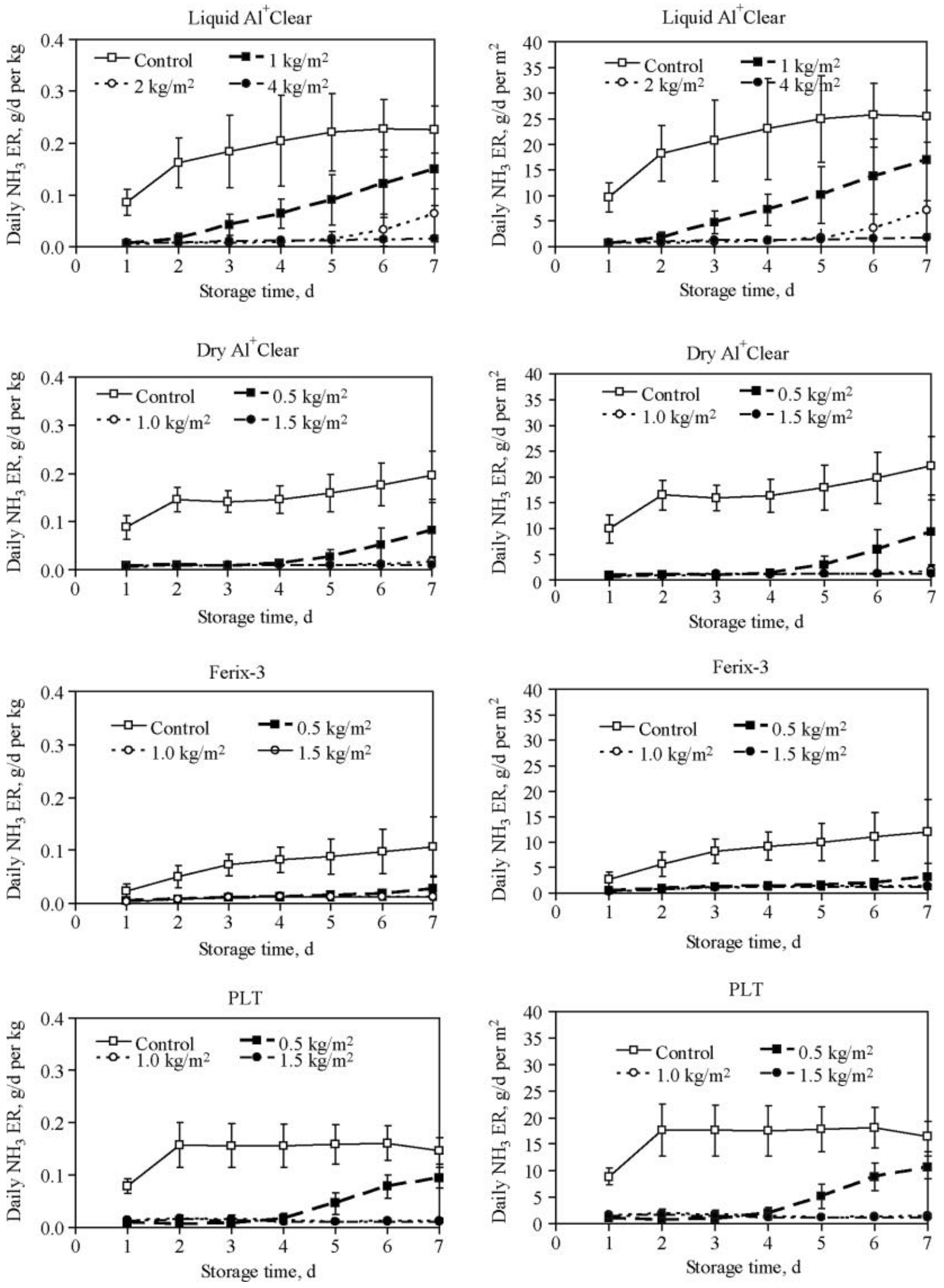

Figure 4. Daily ammonia emission rate (ER; mean and SE, n = 6) of ventilated storage of laying hen manure with different rates of topical application of liquid Al^{+}Clear, dry granular Al^{+}Clear, Ferix-3, and Poultry Litter Treatment (PLT) [12–14].

Table 3. Effects of topical application of liquid Al^{+}Clear, dry granular Al^{+}Clear, Ferix-3, and Poultry Litter Treatment (PLT)[1] at different rates on reduction of ammonia emission from laying hen manure storage and manure property at the end of 7-d storage

	Liquid Al^{+}Clear				Dry Al^{+}Clear				Ferix-3				PLT			
Variable	Ctrl	1	2	4	Ctrl	0.5	1.0	1.5	Ctrl	0.5	1.0	1.5	Ctrl	0.5	1.0	1.5
Amount of manure, kg	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Surface area, m^2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Application rate, kg/m^2	0	1.0	2.0	4.0	0	0.5	1.0	1.5	0	0.5	1.0	1.5	0	0.5	1.0	1.5
Average daily emission rate over 7 d																
g/kg per d	0.187	0.070	0.020	0.011	0.150	0.029	0.011	0.009	0.075	0.014	0.011	0.010	0.144	0.037	0.014	0.012
g/m^2 per d	21.1	7.87	2.30	1.27	17.0	3.23	1.23	1.07	8.41	1.56	1.19	1.09	16.3	4.18	1.57	1.38
Cumulative emission[2]																
g/kg	1.31	0.49	0.14	0.08	1.05	0.20	0.08	0.07	0.52	0.10	0.07	0.07	1.01	0.26	0.10	0.09
g/m^2	148^{a}	55.1^{b}	16.1^{c}	8.90^{c}	119^{a}	22.6^{b}	8.62^{c}	7.48^{c}	58.8^{a}	10.9^{b}	8.33^{c}	7.60^{c}	114^{a}	29.2^{b}	11.0^{c}	9.64^{c}
Emission reduction,[3] %	—	63^{b}	89^{a}	94^{a}	—	81^{b}	93^{a}	94^{a}	—	82^{b}	86^{a}	87^{a}	—	74^{b}	90^{a}	92^{a}
DM content, %	28.1	29.9	31.1	30.8	27.1	27.9	27.1	30.8	28.3	34.1	31.9	33.9	27.0	29.0	30.5	32.3
Total N, g/kg (as is)	17.6	16.5	21.0	24.1	18.5	18.8	20.0	19.1	21.1	23.0	23.5	24.9	16.6	16.2	21.9	23.4
Total N, g/kg (dry base)	62.6	55.2	67.5	73.5	68.3	67.4	73.8	62.0	74.6	67.4	73.7	73.5	61.5	55.9	71.8	72.4
TAN,[4] g/kg (as is)	10.5	9.8	6.0	5.4	11.1	12.5	12.3	10.4	13.2	8.6	7.1	5.6	10.5	8.6	7.3	6.0
TAN, g/kg (dry base)	37.4	32.8	19.3	16.5	41.0	44.8	45.4	33.8	46.6	25.2	22.3	16.5	38.9	29.7	23.9	18.6
pH	7.6	7.53	7.01	6.42	7.68	7.65	7.05	6.82	7.37	7.2	6.92	6.55	7.6	7.3	6.8	6.7
pH of fresh manure	7.2				7.4				7.0				7.5			

[a–c]Means in a row, within a treatment additive, having different superscripts are significantly different ($P < 0.05$).

[1][12–14].

[2]Total cumulative emission reduction of 7 d.

[3]Calculated as: $\text{Emission reduction rate}\ (\%) = \frac{\text{CumulativeEmission}_{\text{Control}} - \text{CumulativeEmission}_{\text{Treatment}}}{\text{CumulativeEmission}_{\text{Control}}} \times 100.$

[4]TAN = total ammonia nitrogen.

ble 3). Specifically, the Ctrl, least, medium, and greatest dosage regimens had a TAN content of 11.3, 9.9, 8.2, and 6.9 g/kg (as is), respectively; pH of 7.6, 7.4, 7.0, and 6.6, respectively ($P < 0.001$); and total N content of 18.5, 18.6, 21.6, and 22.9 g/kg (as is; $P = 0.058$). The data follow the interrelationships among TAN, pH, and N concentrations of the manure. Lowering manure pH decreases uric acid decomposition, which in turn results in less TAN formation, less NH_3 emission, and more N retention in the manure.

As described previously, the granular Al^+Clear, Ferix-3, and PLT at 2 application rates (0.5 or 1.0 kg/m^2, 0.10 or 0.20 lb/ft^2) were further tested to compare NH_3 emission reduction among the additives over a 7-d storage period, involving the same batch of hen manure for each trial. During the first 3-d storage period, there was no difference in NH_3 emission rates among all the applications. Ammonia emissions for the lower application rate (0.5 kg/m^2) started to increase on d 4, 4, and 5 for PLT, Ferix-3, and Al^+Clear, respectively (Figure 5). At the end of the 7-d storage period, NH_3 emission reduction for the greater application rate (1.0 kg/m^2) with Al^+Clear, Ferix-3, and PLT was 92 ± 3, 90 ± 1, and 81 ± 2%, respectively, which was significantly greater than the reduction of 63 ± 8, 42 ± 26, and 56 ± 18%, respectively, for the lower application rate (0.5 kg/m^2; Table 4). There was no significant difference in NH_3 emission reduction over the 7-d period among the 3 additives at 0.5 kg/m^2 dosage ($P = 0.40$). However, at the 1.0 kg/m^2 dosage, NH_3 emission reduction for Al^+Clear (92 ± 3%) or Ferix-3 (90 ± 1%) was greater than that for PLT (81 ± 2%; $P < 0.01$). The NH_3 emission reductions observed in this experiment of the study were slightly different from those observed in the tests of dosage effects described earlier. Several factors could have contributed to the outcome [e.g., differences in manure properties (pH, moisture content) among the trials because of changes in dietary nutrition and environmental conditions and homogeneity of the collected manure among the trials].

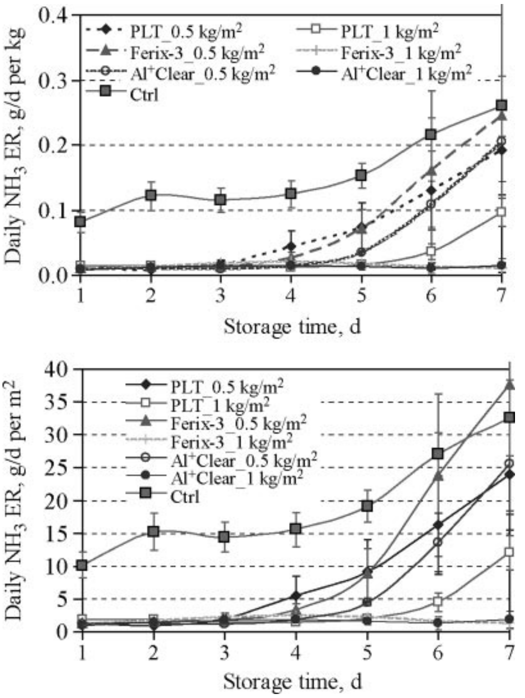

Figure 5. Comparison of daily ammonia emission rate (ER; mean and SE, n = 3) of ventilated storage of laying hen manure with different rates of topical application of granular Al^+Clear, Ferix-3, and Poultry Litter Treatment (PLT) [12–14].

Table 4. Comparison of ammonia emission reduction rate (%; mean ± SD) of topically applied granular Al^+Clear, Ferix-3, and Poultry Litter Treatment (PLT)[1] at application rates of 0.5 or 1.0 kg/m^2

	PLT		Ferix-3		Granular Al^+Clear	
Item	0.5 (0.1 lb/ft^2)	1 (0.2 lb/ft^2)	0.5 (0.1 lb/ft^2)	1 (0.2 lb/ft^2)	0.5 (0.1 lb/ft^2)	1 (0.2 lb/ft^2)
Manure storage time, d						
1	86 ± 2	81 ± 3	87 ± 3	89 ± 2	89 ± 1	91 ± 1
2	91 ± 1	85 ± 2	88 ± 3	89 ± 1	90 ± 1	91 ± 1
3	89 ± 1	87 ± 3	88 ± 3	87 ± 1	91 ± 1	89 ± 1
4	82 ± 5	88 ± 3	86 ± 1	86 ± 2	90 ± 1	89 ± 1
5	74 ± 10	88 ± 2	77 ± 6	86 ± 2	87 ± 2	90 ± 2
6	65 ± 14	87 ± 2	60 ± 16	88 ± 1	77 ± 5	91 ± 2
7	56 ± 18^c	81 ± 2^{ab}	42 ± 26^c	90 ± 1^a	63 ± 8^{bc}	92 ± 3^a

$^{a–c}$Means in a row not having a common superscript are significantly different ($P < 0.05$).

[1][12–14].

It should be noted that the promising efficacies of the tested additives in decreasing NH_3 emissions from hen manure storage were quantified using relatively small laboratory-scale tests. Hence, these results should be considered as preliminary when attempting to apply such treatment agents in the field. In fact, it is highly advisable to expand the evaluation to field scale and verify the efficacies and more importantly assess the costs associated with such application before considering adoption at commercial production settings. The field test should also evaluate the manure properties of the entire storage heap, as opposed to just the top layer, to better assess the fertilizer value of the final product.

CONCLUSIONS AND APPLICATIONS

1. Topical application of zeolite, Al^+Clear, Ferix-3, and PLT onto nearly 1-d-old laying hen manure led to considerable reduction in NH_3 emission from the stored manure.
2. The magnitude of NH_3 emission reduction increases with application rate of the additives to a certain degree. Beyond the threshold, additional application would result in little further reduction in NH_3 emission. In this research, the medium and high application rates (1.0 and 1.5 kg/m^2, 0.2 and 0.3 lb/ft^2) were shown to yield similar NH_3 emission reduction for the tested chemical additives of granular Al^+Clear, Ferix-3, and PLT.
3. When applied at the rate of 0.5 kg/m^2, granular Al^+Clear, Ferix-3, and PLT showed no significant difference in reduction of NH_3 emission from the hen manure over a 7-d storage period. However, when applied at 1.0 kg/m^2, Al^+Clear and Ferix-3 showed greater NH_3 emission reduction than PLT.
4. The laboratory-scale findings of emission reduction by the additives should be considered to be preliminary if the additives are to be applied under commercial production settings. In fact, follow-up field-scale verification tests are warranted and recommended.

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