ENVIRONMENT AND HEALTH

Evaluation of Chemical Amendments to Reduce Ammonia Volatilization from Poultry Litter[1]

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ABSTRACT Ammonia volatilization from poultry litter often causes high levels of atmospheric ammonia in poultry houses, which is detrimental to both farm workers and birds. Ammonia emissions from houses also aggravate environmental problems, such as acid rain, and result in a loss of fertilizer nitrogen. The objectives of this study were to determine the effect of litter amendments on ammonia volatilization and to determine the effect of these amendments on nitrogen and phosphorus content in litter. The results of this research indicate that alum [$Al_2(SO_4)_3 \cdot 18H_2O$], ferrous sulfate ($FeSO_4 \cdot 7H_2O$), and phosphoric acid ($H_3PO_4$) dramatically reduce ammonia volatilization from litter. The amount of ammonia lost from litter treated with sodium bisulfate ($NaHSO_4$) and a proprietory product made of Ca-Fe silicate with a phosphoric acid coating was not different from the control (untreated litter). Aluminum sulfate (alum) and ferrous sulfate also reduced water soluble P concentrations in litter, whereas phosphoric acid greatly increased water-soluble P levels. The most effective compound evaluated with respect to reducing both ammonia loss and P solubility was alum.

(*Key words*: acid rain, alum, eutrophication, litter amendments, manure)

1996 Poultry Science 75:315–320

INTRODUCTION

With the predominant system used for broiler production, a bedding material such as wheat straw, rice hulls, peanut hulls, sawdust, or wood shavings is added to the floor of poultry houses and five or six flocks of broilers are grown on it over a 1-yr cycle. After that time, the litter is removed and applied to farmland as fertilizer. Using the same litter for several flocks results in the production of ammonia gas, which can be produced in high quantities in poultry houses. For over 30 yr, researchers have known that buildup of ammonia levels in poultry rearing facilities adversely affects poultry (Anderson *et al.*, 1964a).

Research on the effects of ammonia on poultry has shown that ammonia causes decreased growth rates (Charles and Payne, 1966a; Quarles and King, 1974; Reece *et al.*, 1980), reduced feed efficiency (Caveny and Quarles, 1978; Caveny *et al.*, 1981), decreased egg production (Charles and Payne, 1966b; Deaton *et al.*, 1984), damage to the respiratory tract (Anderson *et al.*, 1964a; Nagaraja *et al.*, 1983), increased susceptibility to Newcastle disease (Anderson *et al.*, 1964b), increased incidence of airsacculitis (Kling and Quarles, 1974; Quarles and Kling, 1974; Oyetunde *et al.*, 1976), increased levels of *Mycoplasma gallisepticum* (Sato *et al.*, 1973), and increased incidence of keratoconjunctivitis (Bullis *et al.*, 1950; Faddoul and Ringrose, 1950). Due to the reasons listed above, Carlile (1984) suggested that 25 ppm ammonia should not be exceeded in poultry houses.

Attempts to inhibit ammonia volatilization from poultry litter were first reported in the 1950s (Cotterill and Winter, 1953). Since that time, many different chemicals have been tested for their effectiveness in inhibiting ammonia release from poultry litter. Carlile (1984) indicated that these chemicals fall into two categories, those which act by inhibiting microbial growth (which would slow uric acid decomposition) and those that combine with the released ammonia and neutralize it. These chemicals include paraformaldehyde (Seltzer *et al.*, 1969), zeolites like clinoptilolite (Nakaue *et al.*, 1981), superphosphate (Cotterill and Winter, 1953; Reece *et al.*, 1979), phosphoric acid (Reece *et al.*, 1979), ferrous sulfate (Huff *et al.*, 1984), hydrated lime, limestone, gypsum (Cotterill and Winter, 1953), yucca

Received for publication May 12, 1995.
Accepted for publication July 10, 1995.

[1]Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the USDA and does not imply its approval to the exclusion of other products that may be suitable.

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saponin (Johnston *et al.*, 1981), acetic acid, propionic acid (Parkhurst *et al.*, 1974), and antibiotics (Kitai and Arakawa, 1979).

Inhibiting ammonia volatilization from poultry litter with chemical amendments has been shown to increase productivity. Moore *et al.* (1995b) evaluated alum applications to poultry litter in 10 commercial broiler houses at two farms for a 1-yr period. We found weight gains were significantly higher in houses with alum-treated litter than in control houses (1.78 vs 1.72 kg per bird, respectively). Feed conversion was also better for birds grown on litter treated with alum (1.83 vs 1.89 kg/kg, respectively, for alum-treated and control houses). One of the integrators in that study found that birds grown in alum-treated houses could be harvested 1 d earlier than the controls, resulting in substantial savings on feed.

Ammonia volatilization from poultry litter has also been shown to be detrimental to the environment due to its effect on acid atmospheric deposition. Ap Simon *et al.* (1987) stated that ammonia plays a key role in acid rain production and the dominant source of atmospheric ammonia in Europe was livestock wastes, with long-term trends showing a 50% increase in ammonia emissions in Europe from 1950 to 1980. van Breemen *et al.* (1982) stated that ammonia raises the pH of rainwater, which allows more SO_2 to dissolve in it, eventually forming ammonium sulfate, which releases nitric and sulfuric acid in soils upon oxidation. Ammonia volatilization also greatly increases atmospheric N fallout, which contributes to eutrophication. Schroder (1985) indicated that N deposition from wet fallout tripled from 1955 to 1980 and corresponded to N losses from agriculture during this period.

Another environmental problem currently facing the poultry industry is P runoff from fields receiving poultry litter. Phosphorus is considered to be the primary element of concern with respect to eutrophication of freshwater systems (Schindler, 1977). Recent studies have shown extremely high P concentrations in the runoff water from pastures receiving low to moderate levels of poultry litter (Edwards and Daniel, 1992a,b, 1993). The majority (80 to 90%) of the P in the runoff water is dissolved reactive P (Edwards and Daniel, 1993), which is the form that is most readily available for algal uptake (Sonzogni *et al.*, 1982). The threat of eutrophication due to P runoff has resulted in limits being placed on the amount of animal units produced per area of land in The Netherlands.

Research conducted in our laboratory indicates that both phosphorus runoff and ammonia volatilization can be greatly reduced with the addition of chemical amendments to poultry litter, (Moore and Miller, 1994; Moore *et al.*, 1995a; Shreve *et al.*, 1995). There are also several commercial litter amendments currently on the market, among these are products composed of sodium silicate and ethylene glycol, sodium bisulfate, yucca plant extracts, and Ca/Fe silicates with phosphoric acid as a coating. Phosphoric acid is used by growers from at least two of the integrators in the Delmarva area to control ammonia levels in poultry houses. Moore *et al.* (1995a) found that a product composed of sodium silicate and ethylene glycol increased, rather than decreased, ammonia losses from litter. The objectives of this study were to determine the effect of litter amendments on ammonia volatilization, and to determine the effect of these amendments on N and P transformations in litter.

MATERIALS AND METHODS

Poultry litter was collected from a commercial poultry house that had been used to raise four flocks of broilers to 6 wk of age. The litter was collected 4 d after the birds were removed. The bedding of the litter was rice hulls. One hundred grams dry weight equivalent of fresh litter (123 g moist) was weighed into each of 44 750-mL air-tight plastic containers. The treatments were as follows: 1) control: litter alone, 2) 65 g $Al_2SO_4\cdot18H_2O$/kg litter, 3) 130 g $Al_2SO_4\cdot18H_2O$/kg litter, 4) 65 g $FeSO_4\cdot7H_2O$/kg litter, 5) 130 g $FeSO_4\cdot7H_2O$/kg litter, 6) 50 g $FeCl_3$ (wet)/kg litter, 7) 100 g $FeCl_3$ (wet)/kg litter, 8) 20 g H_3PO_4/kg litter, 9) 40 g H_3PO_4/kg litter, 10) 4 g Ca-Fe silicate with phosphoric acid coating/kg litter, and 11) 20 g $NaHSO_4$/kg litter. There were four replications per treatment. The $FeCl_3$ solution was approximately 30% $FeCl_3$. Care was taken to topdress both treatments 10 and 11, rather than to incorporate them into the litter, as recommended by the manufacturers, whereas the other treatments were incorporated into the litter. In an earlier study, these two products were incorporated into the litter, rather than topdressed, with no apparent effect on efficacy (P. A. Moore, Jr., unpublished data).

The containers were equipped with air inflows and outflows. The samples were incubated at 22 ± 3 C and ammonia-free air (i.e., air that had passed through two consecutive 1 *M* HCl traps and one trap containing deionized water) was continuously passed through each chamber and any ammonia volatilized from the litter was trapped in two consecutive boric acid traps containing 30 mL of 0.32 *N* H_3BO_4 solution each. At each sampling period, the boric acid was removed and replaced with new acid. The traps were titrated with 0.10 *N* HCl to determine the ammonia content. Samples were titrated daily for the first 19 d and every other day thereafter. The study was carried out for 42 d. At this time, a 20-g subsample of the litter was obtained after the samples had been thoroughly stirred to insure homogeneity. The samples were extracted with 200 mL of deionized water for 2 h. The samples were centrifuged at 6,000 rpm and aliquots were taken for pH, electrical conductivity (EC), alkalinity, NH_4, NO_3, and dissolved reactive P (DRP).

Samples for EC, pH, and alkalinity were analyzed immediately in an unfiltered state. Samples for NH_4 and NO_3 were filtered through a 0.45 μm filter and frozen.

Ammonium was determined with the salicylate-nitroprusside technique, according to the Environmental Protection Agency (EPA) method 351.2 (U.S. EPA, 1979). Nitrate (+nitrite) was determined using the Cd reduction method, according to Method APHA 418-F (American Public Health Association, 1992). Nitrate concentrations were very low (<1% of inorganic N) and are not reported. Dissolved reactive P samples were filtered (.45 μm), acidified to pH 2.0 with HCl and frozen. Dissolved reactive P was determined using the ascorbic acid technique with an auto-analyzer according to APHA method 424-G (American Public Health Association, 1992). After extraction with water, the litter was extracted with 1 *N* KCl for 2 h, for exchangeable ammonium. After centrifuging, these samples were filtered and analyzed for ammonium as above.

Ten-gram subsamples were taken from each container for water content, total P, and total N analysis. Total N was determined by Kjeldahl distillation after using the salicylic acid modification of the Kjeldahl digestion to include NO_3 (Bremner and Mulvaney, 1982) using moist samples (values were corrected for water content). Moist samples were used, rather than dried, because oven drying resulted in N losses. Total P was determined by digesting oven-dried (60 C) litter with HNO_3 and analyzing the digested sample using inductively coupled argon plasma emission spectrometry (ICP) (Zarcinas *et al.*, 1987). Treatment means were compared for significance ($P \leq 0.05$) using Fisher's Protected Least Significant Difference Test, which was calculated after statistical differences were demonstrated using analysis of variance. All statistical analyses were conducted using SAS® (SAS Institute, 1985).

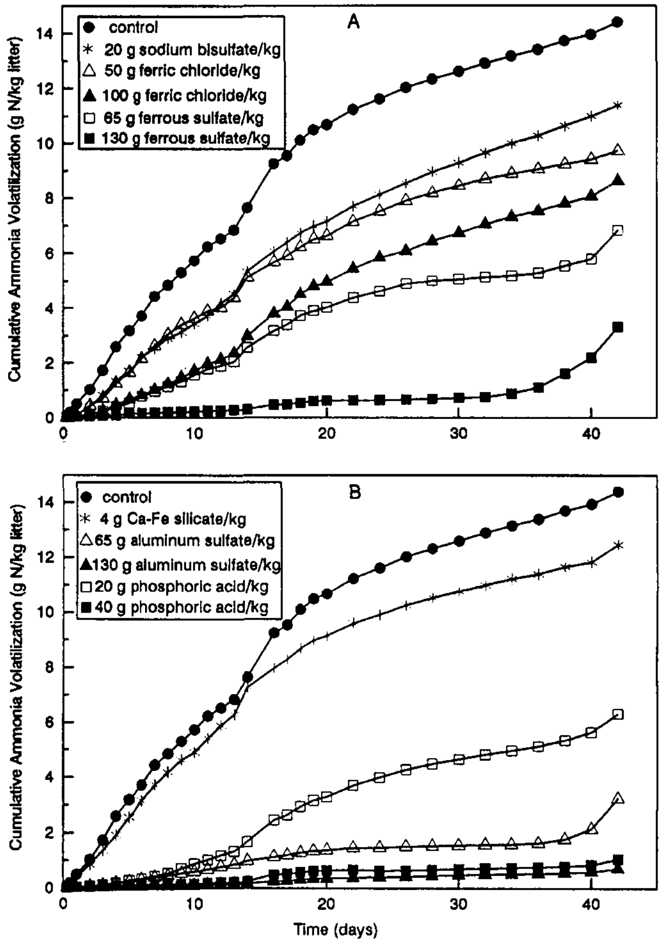

FIGURE 1. Cumulative ammonia volatilization from poultry litter with and without litter amendments as a function of time ($LSD_{0.05}$ = 3.41 at 42 d, pooled SEM = 1.19).

RESULTS AND DISCUSSION

Cumulative ammonia volatilization from the various treatments is shown in Figure 1. The controls lost an average of 14.4 g N/kg litter during the 42-d incubation period; the highest of any treatment. Moore *et al.* (1995a) reported a very similar amount of N volatilized as ammonia from control litter in an earlier study (14.8 g N/kg litter in 42 d).

Cumulative ammonia losses totalling 12.3 and 11.4 g N/kg litter were observed with the Ca/Fe silicate with phosphoric acid coating, and $NaHSO_4$ compounds, respectively. These losses were not different from the control litter (14.4 g N/kg). It is possible that the $NaHSO_4$ was not activated, as addition of water (via foggers) is often required for activation of this compound. However, the air passing through the containers in this study was saturated with water, which should have provided plenty of moisture for activation. Both ferric chloride and ferrous sulfate treatments resulted in significantly lower ammonia volatilization than the controls (Figure 1A). Ammonia losses from the ferric chloride treatments were 9.72 and 8.64 g N/kg litter for the 50 and 100 g $FeCl_3$ treatments, respectively. These losses were somewhat higher than that observed for the ferrous sulfate treatments (6.83 and 3.31 g N/kg litter for the 65 and 130 g ferrous sulfate, respectively). The best two treatments tested were alum and phosphoric acid (Figure 1B). Ammonia losses from the alum-treated litter were 4.07 and 0.7 g N/kg litter, for the 65 and 130 g alum treatments, respectively, whereas losses from the phosphoric acid treated litter were 6.32 and 1.05 g N/kg litter for the 20 g and 40 g H_3PO_4 treatments, respectively.

Treatments that had high rates of volatilization, such as the controls, had the lowest amount of total inorganic N and water-soluble ammonium, as would be expected (Table 1). Conversely, treatments that inhibited volatilization, such as the high rates of alum, ferrous sulfate, and phosphoric acid, resulted in significantly higher concentrations of inorganic N in the litter at 42 d. The high rates of alum and phosphoric acid also had the lowest litter pH. The rate of ammonia volatilization is dependent on pH, moisture content, wind speed, ammonium concentration, and temperature (Reddy *et al.*, 1979). Volatilization increases with increases in any of these variables. The pH of litter is very important because it determines the ratio of ammonia:ammonium. As pH increases, this ratio increases, causing volatiliza-

TABLE 1. Effect of litter amendments on selected litter characteristics after 42 d

Treatment	pH	TIN[1]	NH_4	DRP[2]
		(g/kg)		
Control	8.75[a]	5.19[d]	3.27[d]	1.70[c]
65 g $Al_2(SO_4)_3 \cdot 18H_2O$/kg	8.17[bc]	11.6[b]	8.81[b]	0.74[d]
130 g $Al_2(SO_4)_3 \cdot 18H_2O$/kg	7.45[d]	14.3[a]	11.2[a]	1.17[d]
65 g $FeSO_4 \cdot 7H_2O$/kg	8.28[bc]	8.42[c]	5.94[c]	0.92[d]
130 g $FeSO_4 \cdot 7H_2O$/kg	8.03[c]	13.5[a]	10.8[a]	0.75[d]
50 g liquid $FeCl_3$/kg	8.41[b]	5.86[d]	3.91[d]	1.13[d]
100 g liquid $FeCl_3$/kg	8.27[bc]	7.90[c]	5.63[c]	.73[d]
20 g concentrated H_3PO_4/kg	8.17[bc]	8.74[c]	5.86[c]	6.32[b]
40 g concentrated H_3PO_4/kg	7.60[d]	13.0[a]	10.1[a]	11.6[a]
4 g Ca-fe silicate with H_3 PO_4/kg/kg	8.80[a]	5.11[d]	3.31[d]	1.77[c]
20 g $NaHSO_4$/kg	8.22[bc]	5.66[d]	3.91[d]	1.75[c]
Pooled SEM	0.08	0.47	0.41	0.16

[a–d]Means within the same column with no common superscript differ significantly ($P < .05$).

[1]TIN = Total inorganic N = sum of water soluble and exchangeable NH_4 N.

[2]DRP = Dissolved reactive phosphorus.

tion to increase and vice versa. The pH of the litter surface of the two treatments that were top-dressed (Ca-Fe silicate with phosphoric acid and $NaHSO_4$) may have been lower than the values shown in Table 1, as these values represent the pH of the whole sample.

Increasing the N content of litter should help improve crop yields on fields fertilized with litter. This was shown by Shreve *et al.* (1995), who found that fescue fertilized with poultry litter treated with alum had significantly higher yields than litter treated with ferrous sulfate or litter alone. Nutrient analysis of the fescue revealed that the forage fertilized with alum-treated litter had significantly higher N contents than forage fertilized with normal litter.

In Table 2 the cost of treating a poultry house that is 122 m long and 12 m wide for one growout with these amendments is given. The cost for treating with liquid ferric chloride was estimated to be the same as that required for phosphoric acid, because custom applicators would more than likely be required to apply a liquid. In order to make a proper comparison, the products' effectiveness must be taken into account. This was done by calculating the cost to treat an average house (18,144 kg litter) and dividing that by the amount of N conserved by each treatment. These data indicate that alum, ferrous sulfate, and phosphoric acid are more cost-effective than ferric chloride or the two commercial products tested.

It should be noted that alum and ferrous sulfate would be more desirable than phosphoric acid from an environmental point of view as they would immobilize soluble P in the litter. The dissolved reactive P (DRP) concentrations in litter treated with either of these compounds were significantly lower than the controls, as with $FeCl_3$ (Table 1). Shreve *et al.* (1995) found alum and ferrous sulfate reduced P runoff under field conditions by as much as 87 and 67%, respectively. On the other hand, treatment with phosphoric acid at the recommended rate results in DRP concentrations that are approximately 700% higher than the controls. Such

TABLE 2. Cost and cost-effectiveness of various poultry litter amendments at rates used in this study. Costs are based on recommended rates for one growout in a 1,485 m^2 (16,000 ft^2) house, assuming 20,000 birds produce 18,160 kg of litter

Treatment	Kg/house	Cost/house	Kg N saved[1]	Cost/kg N held
	(kg)	($)	(kg)	($)
Control	. . .	. . .	. . .	. . .
65 g alum/kg	1,179	260	202	1.28
130 g alum/kg	2,359	520	249	2.09
65 g ferrous sulfate/kg	1,179	143	137	1.04
130 g ferrous sulfate/kg	2,359	286	201	1.42
50 g ferric chloride/kg	907	200	85	2.36
100 g ferric chloride/kg	1,814	400	105	3.83
20 g phosphoric acid/kg	363	200	147	1.36
40 g phosphoric acid/kg	726	400	242	1.65
4 g Ca/Fe silicate with H_3PO_4/kg	73	288	34	8.35
20 g $NaHSO_4$/kg	363	144	54	2.67

[1]Amount N conserved was calculated based on the difference in ammonia volatilized between treatments and that observed in the control samples.

high levels of soluble P would result in higher P levels in runoff water from fields. Dissolved reactive P levels were not affected by $NaHSO_4$ or Ca-Fe silicate with phosphoric acid (Table 1).

Although ferrous sulfate has been used in the past to control ammonia, cases of catastrophic mortality have been reported due to iron toxicity (Wallner-Pendleton *et al.*, 1986; Pescatore and Harter-Dennis, 1989). Research conducted in our laboratory (P. A. Moore, Jr., unpublished data) on the effects of litter amendments showed that after 4 wk of growth the cumulative mortality rates of broilers were significantly lower in alum and ferric chloride treated litter than in ferrous sulfate-treated litter (3.6, 4.4, 8.3, and 10.2% for the alum, liquid ferric chloride, control, and ferrous sulfate amendments, respectively). Low mortality in the alum and ferric chloride treatments was believed to be due to the reduction in atmospheric ammonia levels, whereas high mortality in the ferrous sulfate treatment was probably due to Fe toxicity. It should be noted that the rate of Fe applied with liquid ferric chloride was much lower than for ferrous sulfate.

Reece *et al.* (1979) and Anderson *et al.* (1964b) indicated that high ammonia concentrations in poultry houses are more common in the winter because high heating costs force growers to decrease ventilation. Although increased ventilation will solve most of the health problems associated with high ammonia levels in poultry houses, it is costly during winter months. Carr and Nicholson (1980) studied three ventilation rates (low, medium, and high) and found that weight gains were highest with high ventilation rates. However, they calculated the high rate (ventilation needed to keep ammonia levels below about 40 ppm) resulted in an increase in fuel consumption of 172% compared to the medium rate (which had ventilation rates 50% lower). Attar and Brake (1988) developed a computer program that modeled the economic benefits of ammonia control in poultry houses. They calculated that if the outside temperature is 7 C, then the cost of producing broilers increased by $0.11/kg when ammonia concentrations increased from 25 to 85 ppm. In a normal poultry house with 19,000 birds weighing 1.82 kg each, this cost would be roughly equivalent to $3,800 per flock, which is much higher than the cost of alum ($400) if 2 tons were applied per house per flock.

One aspect of high ammonia levels in poultry rearing facilities that is often overlooked is the effect on the grower. Farm workers often spend up to 8 to 10 h/d in poultry houses, particularly when the birds are young. Normally, this period coincides with the highest ammonia levels, at times in excess of 100 ppm. In Europe, COSSH (Control of Substances Hazardous to Health) has set the limit of human exposure to ammonia at 25 ppm for an 8-h day and 35 ppm for a 10-min exposure (Williams, 1992). The effect on humans of years of chronic exposure to relatively high levels of ammonia warrants investigation.

Results from this study indicate that alum, ferrous sulfate, and phosphoric acid have the most efficacy to reduce ammonia volatilization from poultry litter of the compounds tested. Alum and ferrous sulfate would be preferred over phosphoric acid due to the fact that these compounds reduce phosphorus runoff, whereas phosphoric acid would be expected to increase phosphorus runoff. In addition, alum would be preferred over ferrous sulfate, based on concerns over iron toxicity with the use of ferrous sulfate.

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