Effect of Chemical Amendments on Ammonia Volatilization from Poultry Litter

P. A. Moore, Jr.,* T. C. Daniel, D. R. Edwards, and D. M. Miller

ABSTRACT

Ammonia (NH_3) volatilization from poultry litter results in a buildup of atmospheric NH_3 in chicken houses, which is detrimental to both farm laborers and birds. Ammonia loss from litter is detrimental to the external environment because it results in acid rain, as well as low N/P ratios in litter, which increase the likelihood of excessive P runoff into adjacent water bodies. The objectives of this study were to determine the effect of various chemical amendments on NH_3 volatilization and selected litter characteristics after 42 d. A laboratory study was conducted using the following amendments: $Ca(OH)_2$ (calcium hydroxide), $Al_2(SO_4)_3 \cdot 18H_2O$ (alum), alum + $CaCO_3$, $FeSO_4 \cdot 7H_2O$ (ferrous sulfate), and MLT (Multi-purpose Litter Treatment, a commercial product). Ammonia-free air was continuously passed through air-tight chambers containing amended litter and any NH_3 volatilized from the litter was trapped in boric acid solutions, which were titrated daily for NH_3 content. The study was carried out for 42 d. At this time, the litter was analyzed for pH, electrical conductivity (EC), soluble organic C (SOC), metals, and soluble and total forms of N and P. The results of this study indicated that the addition of alum to poultry litter dramatically reduces NH_3 volatilization (up to 99% less volatilization than controls). Decreases in volatilization resulted in higher total and soluble N in litter, which increased N/P ratios. Several of the compounds studied (particularly alum) were effective in decreasing water-soluble P levels in litter. Therefore, we are proposing the use of alum as a litter amendment in poultry houses.

WITH THE CURRENT SYSTEM used for poultry production, a bedding material such as wheat straw, rice hulls, 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 is normally land-applied as fertilizer. This re-use of litter for several flocks results in the production of NH_3 gas, which can be produced in high quantities in poultry houses. For >30 yr, researchers have known that NH_3 levels build up in poultry-rearing facilities, and this buildup adversely affects chickens. Scarborough (1957) and Valentine (1964) both observed NH_3 levels in the 60 to 70 $\mu L\ L^{-1}$ range in the atmosphere of poultry houses. Anderson et al. (1964b) showed that NH_3 levels reached 100 $\mu L\ L^{-1}$ in the atmosphere of commercial poultry houses. In Europe, COSHH (Control of Substances Hazardous to Health) has set the limit of human exposure to NH_3 at 25 $\mu L\ L^{-1}$ for an 8-h day and 35 $\mu L\ L^{-1}$ for a 10-min exposure (Williams, 1992). Reece et al. (1979) and Anderson et al. (1964a) indicated that high NH_3 concentrations in poultry houses are more common in the winter, since the curtains on the houses are closed and high ventilation rates increase energy costs.

Research on the effects of high NH_3 levels on poultry has shown it causes damage to the respiratory tract (Anderson et al., 1964a; Nagaraja et al., 1983), increased susceptibility to Newcastle disease (Anderson et al., 1964a), increased levels of Mycoplasma gallisepticum (Sato et al., 1973), increased incidence of airsaculitis (Kling and Quarles, 1974; Quarles and Kling, 1974; Oyetunde et al., 1976), impaired immunosuppression (Nagaraja et al., 1984), decreased growth rates (Reece et al., 1980; Charles and Payne, 1966a; Quarles and King, 1974), decreased egg production (Deaton et al., 1984; Charles and Payne, 1966b), reduced feed efficiency (Caveny and Quarles, 1978; Caveny et al., 1981), and increased incidence of keratoconjunctivitis (Bullis et al., 1950; Faddoul and Ringrose, 1950).

Due to the reasons listed above, Carlile (1984) indicated that 25 $\mu L\ L^{-1}$ NH_3 should not be exceeded in poultry houses. Attempts to inhibit NH_3 volatilization from poultry litter were first reported in the 1950s (Cotterill and Winter, 1953). Since then, many different chemicals have been tested for their effectiveness to inhibit NH_3 release from litter. Carlile (1984) indicated that these chemicals fall into two categories, those that act by inhibiting microbial growth (which would slow uric acid decomposition) and those that combine with the released NH_3 and neutralize it. These chemicals include calcium chloride (Witter and Kirchmann, 1989), 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 (Cotterill and Winter, 1953), limestone (Cotterill and Winter, 1953), gypsum (Cotterill and Winter, 1953), magnesium salts (Witter and Kirchmann, 1989), yucca saponin (Johnston et al., 1981), acetic acid (Parkhurst et al., 1974), propionic acid (Parkhurst et al., 1974), and antibiotics (Kitai and Arakawa, 1979).

Another detrimental aspect of NH_3 volatilization from litter is the effect on acid atmospheric deposition. ApSimon et al. (1987) indicated that atmospheric NH_3 pollution plays an important role in acid rain. They indicated that the dominant source of NH_3 in Europe was livestock wastes, with long-term trends showing a 50% increase in NH_3 emissions in Europe from 1950 to 1980. Ammonia raises the pH of rainwater, which allows more SO_2 to dissolve in it. Ammonium sulfate then forms, which oxidizes in the soil, releasing nitric and sulfuric acid (van Breemen et al., 1982). This produces two to five times the acid input to soils previously described for acid atmospheric deposition, resulting in extremely low pH values (2.8-3.5) and high levels of dissolved aluminum in noncalcareous soils (van Breemen et al., 1982,

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Abbreviations: MLT, Multi-purpose Litter Treatment; EC, electrical conductivity; SOC, soluble organic carbon; COSHH, Control of Substances Hazardous to Health; DRP, dissolved reactive phosphorus; TDP, total dissolved phosphorus; ICAP, inductively coupled argon plasma; BOD, biochemical oxygen demand.

1989). Ammonia volatilization can also contribute to eutrophication. Nitrogen deposited via wet fallout tripled in Denmark from 1955 to 1980 and corresponded to N losses from agriculture during this period (Schroder, 1985). The rising levels of N in the fallout were also shown to be highly correlated to the NO_3-N content in Danish streams (Schroder, 1985).

Another major problem 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 (80-90%) 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). In the USA, guidelines for confined animal operations are currently being formulated by state and federal agencies, which could limit animal production in certain areas based on threats to surface and/or groundwater.

In light of these developments and the fact that P runoff from fields receiving litter is mostly in the dissolved form, our laboratory has conducted several experiments to determine if P solubility in poultry litter can be reduced with Al, Ca, and/or Fe amendments. These studies have shown that water-soluble P concentrations can be reduced by several orders of magnitude with a variety of amendments (Moore and Miller, 1992, 1994). Although this would be beneficial from an environmental point of view, there is little economic incentive (at present) for growers to decrease P runoff from their land. Therefore, an attempt was made to identify secondary benefits of these litter amendments in an effort to make their use economically feasible. Since NH_3 volatilization is such a large problem in the poultry industry and since this process is largely dependent on pH (which was found to be greatly affected by a variety of amendments), this appeared to be a logical second step. Hence, the objectives of this study were to determine the effect of various chemical amendments on NH_3 volatilization and selected litter characteristics after 42 d.

METHODS AND MATERIALS

Poultry litter was collected from low-ventilation growth chambers that had been used to raise one flock of broilers to 6 wk of age. The litter was collected 2 d after the birds were removed. The bedding of the litter was rice hulls. The moisture content of the litter was high, due to low ventilation rates in the chamber, but the litter was not caked. Ninety-two grams of fresh litter (50 g dry wt. equivalent) was weighted into each of 44, 750-mL air-tight plastic containers. Eleven treatments were utilized in this study (Table 1). There were four replications per treatment. After weighing the litter into the containers, the amendments were added and thoroughly mixed into the litter. The containers were equipped with air inflows and outflows. The samples were incubated at 22°C ± 3° 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 NH_3 volatilized from the litter was trapped in two consecutive boric acid traps containing 30 mL solution each. At each sampling period, the boric acid was removed and replaced with new acid. The traps were titrated with 0.10 *M* HCl to determine the NH_3 content. Before the study, a preliminary experiment was conducted in which boric acid traps were compared to H_2SO_4 traps, which were analyzed using normal Kjeldahl methods. There were no differences from the methods (data not shown), indicating that the trapping capacity of the boric acid was not exceeded as was experienced in a study on NH_3 volatilization from liquid swine manure conducted by O'Halloran (1993). 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 extracted with 200 mL of deionized water for 2 h. The samples were centrifuged at 6000 rpm and aliquots were taken for pH, electrical conductivity (EC), alkalinity, NH_4, NO_3, dissolved reactive P (DRP), total dissolved P (TDP), SOC, and metals.

Samples for EC, pH, and alkalinity were analyzed immediately in an unfiltered state. Samples for NH_4 and NO_3 were filtered through 0.45-μm filter and frozen. Ammonium was determined with the salicylate-nitroprusside technique, according to USEPA method 351.2 (USEPA, 1979). Nitrate (+ nitrite) was determined using the Cd reduction method, according to Method APHA 418-F (APHA, 1992). Nitrate values were very low (<1% of inorganic N) and are not reported. Metal, DRP, and TDP samples were filtered (0.45 μm), acidified to pH 2.0 with HCl, and frozen. Metals and TDP were determined by ICAP (inductively coupled argon plasma emission spectrometer). Dissolved reactive P was determined using the ascorbic acid technique with an auto-analyzer according to APHA method 424-G (APHA, 1992). Soluble organic C was determined according to APHA method 5310-B (APHA, 1992). After the water extract, the litter was extracted with 1 *M* KCl for 2 h for exchangeable NH_4. After centrifuging, these samples were filtered and analyzed for NH_4 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, since 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 ICP (Zarcinas et al., 1987). Fecal coliform counts were made on litter samples from all the treatments at the end of the study and were analyzed by the Arkansas Water Resources Laboratory using the most probable number method. All samples tested negative, indicating that these bacteria do not survive for long periods (6 wk) in environments with relatively high temperatures (22°C). Future work will be conducted to determine the effect of these amendments on short-term coliform viability, since bacterial contamination of rivers and lakes from manure is an important water quality problem.

RESULTS AND DISCUSSION

An average of 14.8 g N kg^{-1} litter was lost from the controls (unamended litter) during the 42-d incubation period (Fig. 1). This corresponds to an NH_3 volatilization rate of 352 mg N kg^{-1} d^{-1}. Applications of MLT actually increased NH_3 volatilization. The recommended rate (10 g MLT kg^{-1}) resulted in 31% more N loss via volatilization than the controls (Fig. 1). At two times the recommended rate (20 g MLT kg^{-1}), volatilization was 15% higher than the controls (Fig. 1). These results are not

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

Treatment	pH	TKN	NH_4†	TP	SOC	DRP	TDP
			g kg^{-1}			mg kg^{-1}	
Control	8.89	26.1	3.72	24.8	27.4	2022	2621
25 g $Ca(OH)_2$ kg^{-1}	9.09	24.8	3.62	23.3	26.7	1305	1798
50 g $Ca(OH)_2$ kg^{-1}	9.03	26.3	5.80	21.9	30.3	989	1324
100 g $Al_2(SO_4)_3 \cdot 18H_2O$ kg^{-1}	8.37	35.7	13.6	22.5	20.7	467	734
200 g $Al_2(SO_4)_3 \cdot 18H_2O$ kg^{-1}	7.07	41.5	17.6	21.6	22.0	111	261
100 g $Al_2(SO_4)_3 \cdot 18H_2O$ + 50 g $CaCO_3$ kg^{-1}	8.07	29.0	10.9	22.5	14.8	431	605
200 g $Al_2(SO_4)_3 \cdot 18H_2O$ + 50 g $CaCO_3$ kg^{-1}	7.88	32.6	16.1	21.4	11.1	194	286
100 g $FeSO_4 \cdot 7H_2O$ kg^{-1}	8.37	30.5	12.1	22.3	19.9	748	978
200 g $FeSO_4 \cdot 7H_2O$ kg^{-1}	8.09	37.5	19.9	21.1	14.6	529	727
10 g MLT kg^{-1}	9.11	27.0	5.21	24.4	24.8	1827	2361
20 g MLT kg^{-1}	9.09	24.6	3.54	23.5	26.4	1788	2245
LSD(0.05)	0.36	2.7	3.16	ns	3.5	211	295

† Sum of water-soluble and exchangeable NH_4-N.

surprising since the pH of MLT is around 10. Increases in litter pH shift the NH_3/NH_4 equilibrium toward NH_3, resulting in higher volatilization.

Ammonia volatilization from litter treated with $Ca(OH)_2$ was not significantly different from that in the controls (Fig. 2). During the first 3 d of the experiment, the rate of NH_3 loss from the 50 g $Ca(OH)_2$ kg^{-1} treatment was much faster than the controls, probably due to increases in pH. However, $Ca(OH)_2$ was probably converted to $CaCO_3$ with time, resulting in lower pHs. The pHs of the $Ca(OH)_2$ treatments were not significantly different from the controls after 42 d of incubation (Table 1).

Applications of $FeSO_4 \cdot 7H_2O$ decreased NH_3 volatilization (Fig. 3). Cumulative NH_3 losses at 42 d were 11 and 58% lower than the controls for the 100 and 200 g $FeSO_4 \cdot 7H_2O$ kg^{-1} treatments, respectively. This is probably due to a decrease in litter pH, since $FeSO_4 \cdot 7H_2O$ is an acid-forming compound. Although ferrous sulfate controls NH_3 emissions, there is a major problem with its utilization as a litter amendment. Wallner-Pendleton et al. (1986) reported a large die-off of 1-day-old chicks in a commercial flock after the litter had been treated with ferrous sulfate. Apparently, chickens normally consume a certain amount of the litter and when it has been treated with ferrous sulfate, it can result in increased mortality of the birds.

Alum applications, both with and without $CaCO_3$, greatly reduced NH_3 volatilization (Fig. 4). Nitrogen losses at 42 d with alum (at rates of 100 and 200 g alum kg^{-1}), in combination with 100 g $CaCO_3$, were 24 and 57% lower than the controls, respectively. When alum was applied alone the N loss was greatly reduced, with cumulative NH_3 losses at Day 42 that were 36 and 99% lower than the controls for the 100 and 200 g alum kg^{-1} treatment, respectively. In fact, only 0.2 g N kg^{-1} was lost due to NH_3 volatilization at the high rate of alum and this occurred in the last week of the study. Before that time, NH_3 loss from the 200 g alum kg^{-1} treatment had been zero.

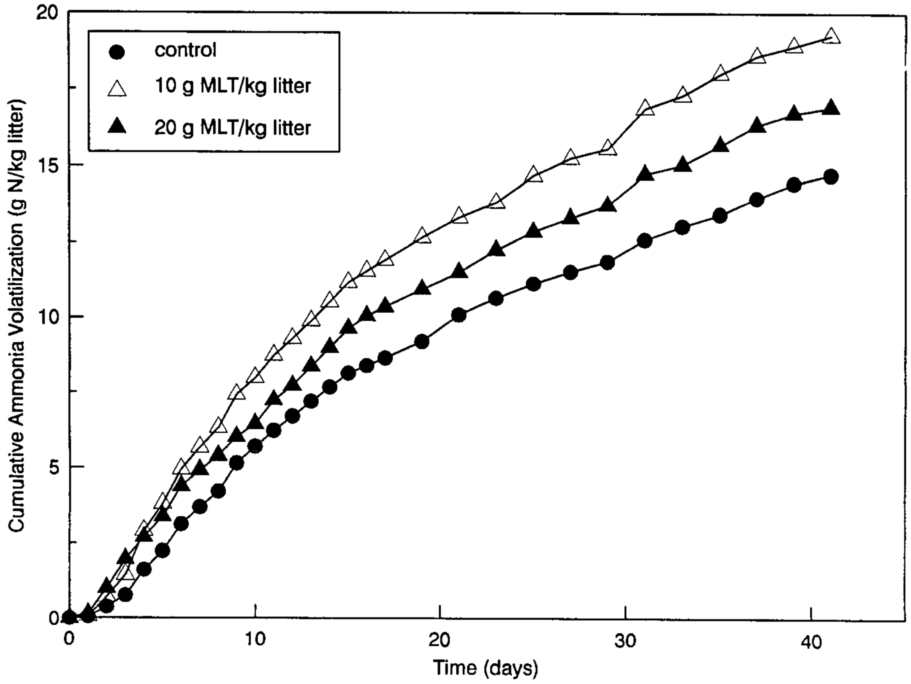

Fig. 1. Cumulative ammonia volatilization from poultry litter with and without MLT amendments as a function of time [LSD(0.05) at Day 42 = 5.41].

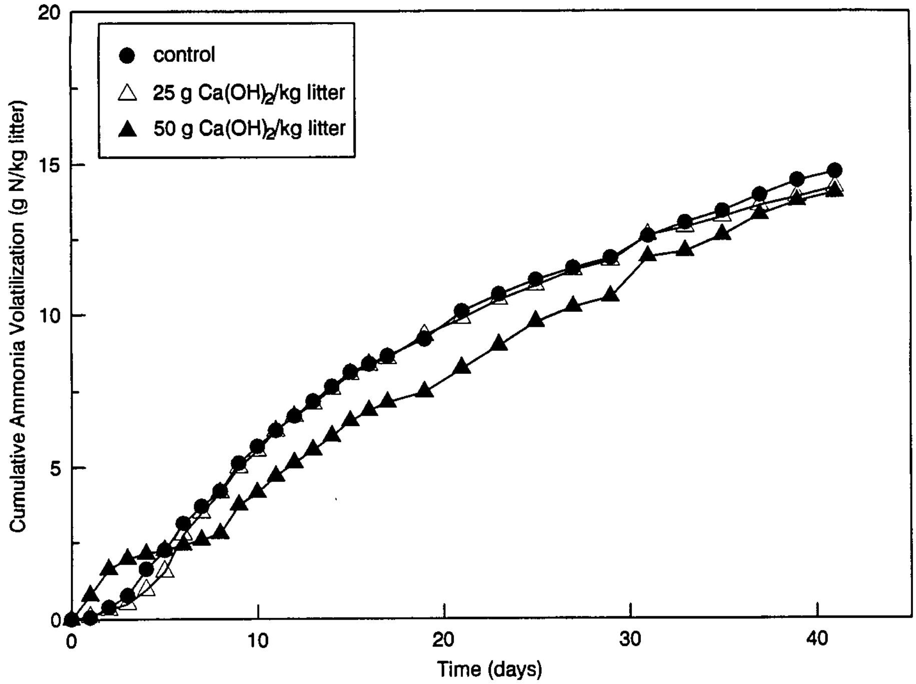

Fig. 2. Cumulative ammonia volatilization from poultry litter with and without calcium hydroxide amendments as a function of time [LSD(0.05) at Day 42 = 5.41].

In Fig. 5, the total N concentrations of the litter after 42 d of incubation is plotted as a function of the cumulative NH_3 volatilization for the various treatments. Treatments with higher volatilization had lower total N concentrations at the end of the study, as would be expected. Most of the additional N in the treatments with low volatilization was NH_4-N (Table 1). Less than 1% of the inorganic N was present as NO_3-N (data not shown). The total N concentration of the 200 g alum kg^{-1} treatment was 41.5 g N kg^{-1}. This was somewhat higher than the original N concentration (38.5 g N kg^{-1}) and significantly higher than any of the other treatments. If the weight of alum present had been taken into account, the N concentrations of the litter itself would have been in excess of 50 g N kg^{-1}. Higher total N concentrations at the end of the study than the original litter are probably

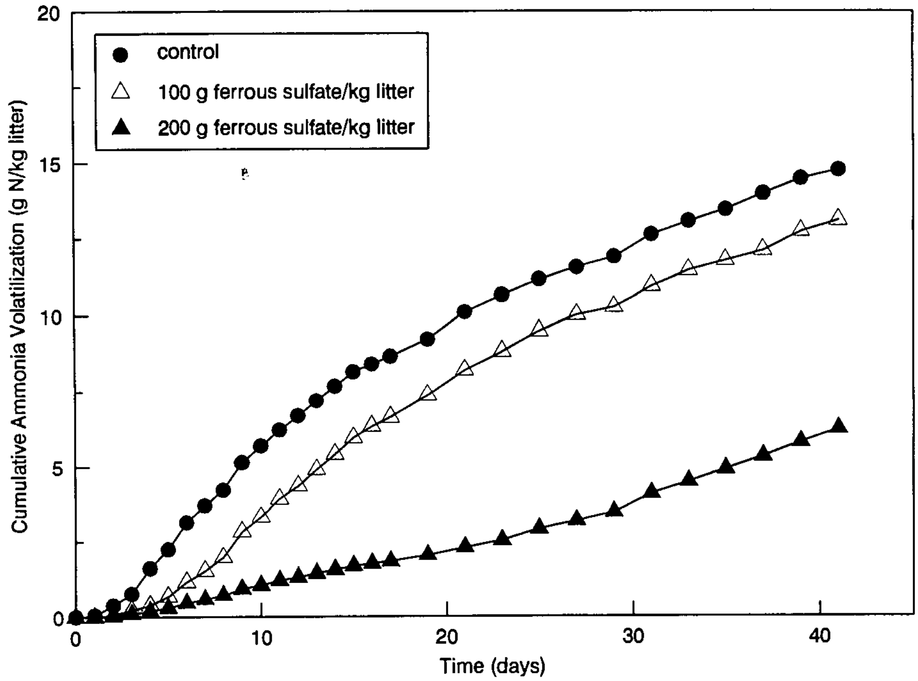

Fig. 3. Cumulative ammonia volatilization from poultry litter with and without ferrous sulfate amendments as a function of time [LSD(0.05) at Day 42 = 5.41].

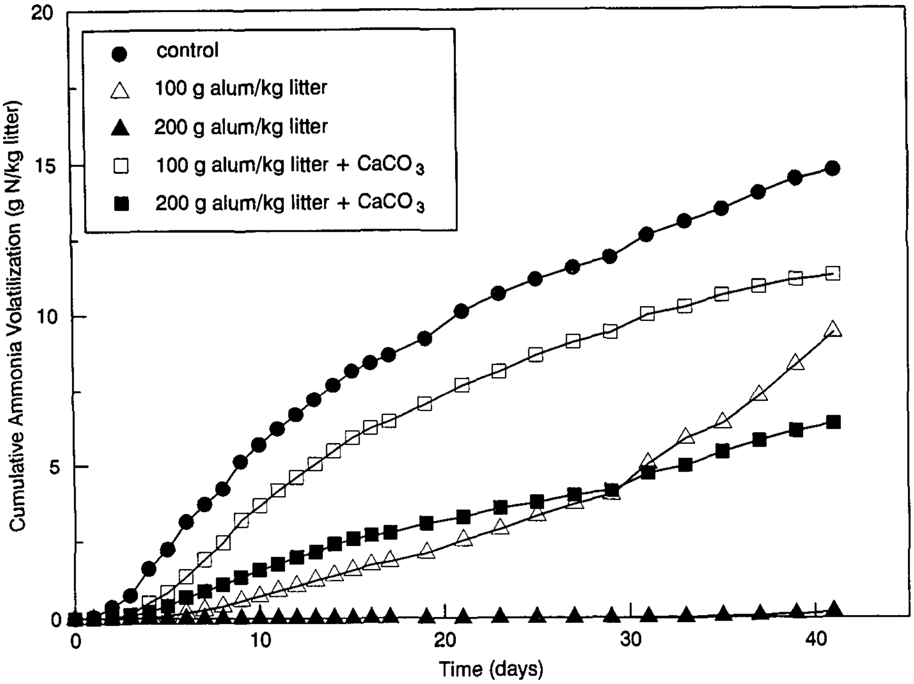

Fig. 4. Cumulative ammonia volatilization from poultry litter with and without aluminum sulfate amendments as a function of time [LSD(0.05) at Day 42 = 5.41].

the result of losses of C via CO_2 evolution from microbial decomposition. The controls contained 26.1 g N kg^{-1} at the conclusion of the study. Therefore, the addition of alum at the higher rate resulted in a doubling of the N concentrations in the litter, which would greatly increase the value of poultry litter as a fertilizer source.

Research by Moore et al. (1994, 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 compared with that treated with ferrous sulfate (3.6, 4.4, 8.3, and 10.2% for the alum, liquid ferric chloride, control, and ferrous sulfate amendments, respectively). Low mortality rates in the alum and ferric chloride treatment compared with the controls were probably due to decreased levels of atmospheric NH_3, whereas high mortality in the ferrous sulfate treatment was probably due to Fe toxicity (the rate of Fe applied from the liquid ferric chloride was much lower than for ferrous sulfate). These results support the findings of Wallner-Pendleton et al. (1986) and indicate that ferrous sulfate is not a suitable amendment for poultry litter.

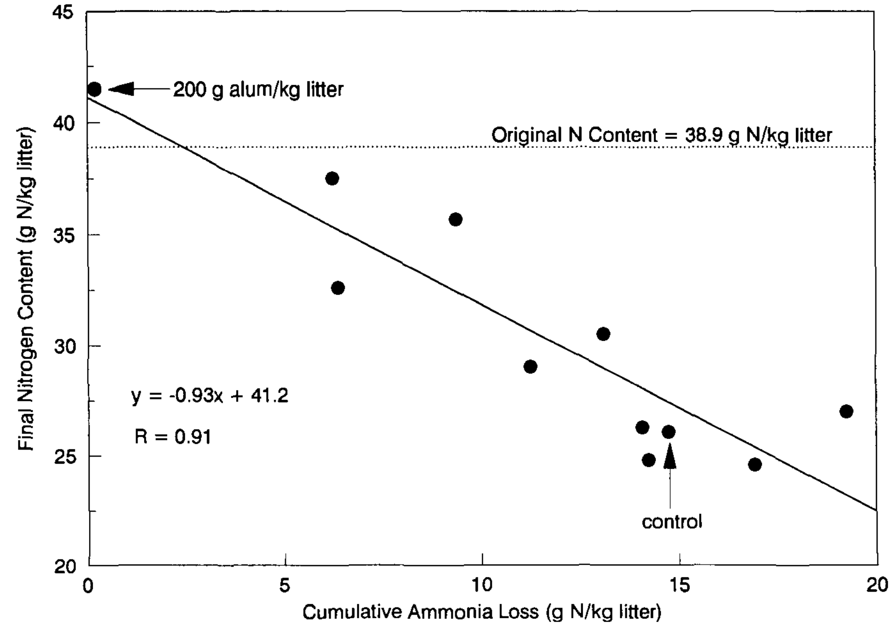

Fig. 5. Total N content of the litter after 42 d of incubation as a function of the cumulative ammonia volatilization from the various treatments.

The rate of NH_3 volatilization is highly dependent on pH. As pH increases, the NH_3/NH_4 ratio increases, causing volatilization to increase. Reece et al. (1979) indicated that NH_3 volatilization in poultry litter increases dramatically at pHs above 7. Therefore, acid-forming compounds, like alum and ferrous sulfate, reduce volatilization, whereas basic compounds like MLT (which has a pH of 10) increase volatilization. The high rate of alum resulted in the lowest litter pH (7.07), which was significantly lower than the other treatments. This treatment also resulted in the lowest alkalinity (data not shown).

Although increased ventilation will solve most of the health problems associated with high NH_3 levels in poultry houses, it is expensive during winter months, due to energy costs. 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 that the high rate (ventilation needed to keep NH_3 levels below about 40 $\mu L\ L^{-1}$) resulted in an increase in fuel consumption of 172% compared with the medium rate (which had ventilation rates 50% lower). Attar and Brake (1988) developed a computer program that modelled the economic benefits of NH_3 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^{-1} when NH_3 concentrations increased from 25 to 80 $\mu L\ L^{-1}$. In a normal poultry house with 19 000 birds weighing 1.82 kg each, this cost would be roughly equivalent to \$3800 per flock. The cost of treating the litter with amendments such as alum would be almost an order of magnitude lower than this.

Dissolved reactive P (DRP) concentrations were lowered by all of the treatments studied except MLT (Table 1). Dissolved P concentrations at the end of the study were significantly lower with the addition of 200 g alum kg^{-1} than any other treatments, either with $CaCO_3$ (194 mg P kg^{-1}) or without (111 mg P kg^{-1}). The water-soluble P levels of these treatments were an order of magnitude lower than the controls (2022 mg P kg^{-1}). Total dissolved P concentrations were somewhat higher, but similar, to DRP levels (Table 1). Alum, calcium hydroxide, ferrous chloride, and ferrous sulfate have all been shown to be effective in decreasing P solubility in poultry litter (Moore and Miller, 1992, 1994). Since the major form of P in runoff from fields fertilized with poultry litter is water-soluble P (Edwards and Daniel, 1993), P runoff from fields receiving litter amended with these compounds should be lower than that from fields fertilized with normal litter. This was confirmed in a field study using rainfall simulators by Shreve et al. (1995), who showed that the P concentrations in runoff from small plots receiving alum-treated poultry litter were 87% lower than plots receiving the same rates of normal litter. Fescue production was also significantly increased with alum-treated litter compared with normal litter, as a result of increased N availability.

Currently, there is concern over P runoff from pastures receiving poultry litter. High concentrations of soluble P have been observed from fields receiving poultry litter. The University of Arkansas Extension Service is recommending growers not apply poultry litter on soils that test 150 kg P ha^{-1} (Mehlich III extractable) or higher due to the concern over eutrophication. Many fields in northwestern Arkansas already test above 500 kg P ha^{-1} and the numbers continue to grow. This could eventually force growers to transport litter to areas that test low in soil P. Although this will probably help the environment, it will, in effect, lower the value of the litter (due to high transportation costs). The growers will also have to buy commercial N fertilizers to meet the N requirements of their pastures.

By treating poultry litter with alum, the amount of P runoff can be decreased dramatically. Results from this study also indicate that the use of alum will benefit poultry production and the environment by significantly reducing NH_3 volatilization from litter. This should not only help improve broiler production costs, it will increase the fertilizer value of the litter by increasing the N content. Currently, more than half of the N in chicken litter is lost via NH_3 volatilization before it can be taken up by forages. This results in a poorly balanced fertilizer source, since the N/P ratio is low. Forages have much higher requirements for N than P; therefore, the best fertilizers should reflect this balance. Since alum would reduce volatilization losses, the litter would be a higher quality fertilizer. This will also result in less atmospheric contamination by NH_3.

Another aspect of air pollution that will be addressed by these amendments is odor. The number one complaint received by state and federal environmental agencies each year against animal producers involves odor. Since NH_3 comprises a portion of the odor associated with poultry litter, measures to control odor must incorporate strategies that reduce NH_3 volatilization.

Since this work was initiated, questions on the environmental impact of these amendments have been raised. For example, will the Al be toxic to grass or fish in streams receiving runoff? Evidence suggests no. As mentioned earlier, fescue production was found to be higher in plots receiving alum-treated litter compared with normal litter (Shreve et al., 1995). Aluminum represents one of the primary components of soils and sediments. Its bioavailability is controlled by pH. Aluminum is not toxic to plants and fish under normal pH conditions (i.e., when soil pH is above about 4.5 and water pH is above pH 5.5). In fact, alum is often used in lake restoration (to precipitate P).

If alum is added to poultry litter after each flock of chickens is grown, then the NH_3 levels in the houses will be lowered for the first few weeks of the next flock. Normally, 1-day-old chicks, which are very susceptible to high NH_3 are placed in the houses. If the litter has been treated with alum, then the pH will start out low (5–6) and increase with time as the acidity from the alum reacts with bases, such as NH_3. Ultimately, all of the acidity will be consumed, causing the pH to increase to over 7 after about 5 wk (Table 1). At such high pHs, concentrations of Al^{3+} are too low to cause problems. Rather, the Al is in the $Al(OH)_3$ form, which is relatively insoluble.

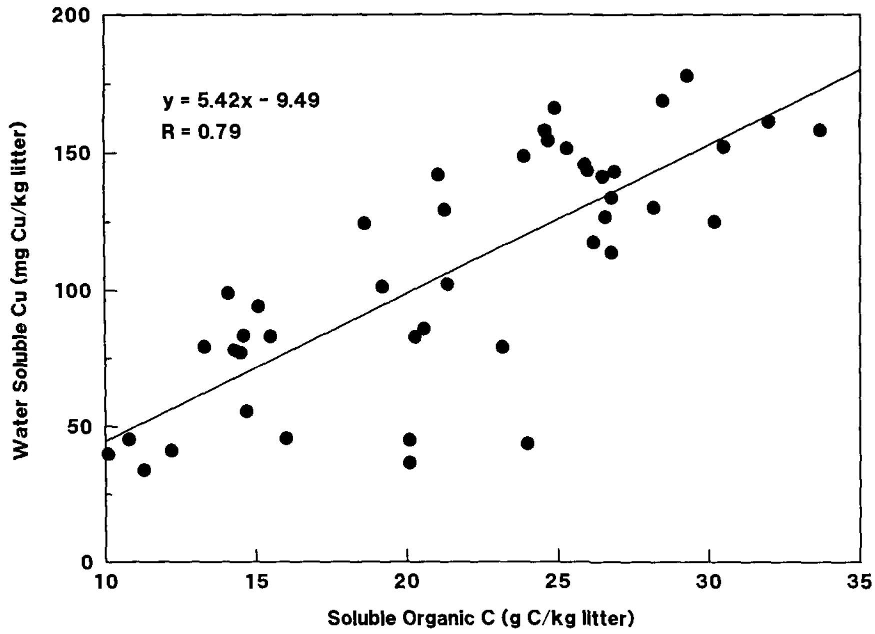

Fig. 6. The relationship between water soluble Cu and soluble organic C in water extracts of poultry litter treated with various compounds.

Moore and Miller (1994) and Shreve et al. (1995) showed SOC levels decreased dramatically with addition of various Al and Fe amendments. This was also found in this study (Table 1). This should help improve the runoff water from fields receiving poultry litter by decreasing the biochemical oxygen demand (BOD) of the runoff. Another important parameter that is affected by SOC is metal solubility. At present, the poultry industry uses large quantities of heavy metals, such as Cu and Zn, as feed additives. Since poultry litter contains extremely high concentrations of soluble organics, these metals become complexed, resulting in unusually high metal solubilities. Therefore, anything that results in decreased SOC levels also decreases heavy metal solubility (Fig. 6). Lower SOC and soluble Cu levels were observed in the alum and ferrous sulfate treatments.

CONCLUSIONS

Results from this study indicated that alum greatly reduced NH_3 volatilization from poultry litter. By decreasing N losses from volatilization, the use of this compound should result in higher total N concentrations in poultry litter, thus increasing its value as a fertilizer. Alum was also shown to decrease the solubility of P in litter. Since high NH_3 levels in poultry houses cause major economic losses to producers, the use of alum as a litter amendment should result in increased poultry productivity, while decreasing the negative environmental impact caused by P runoff from land application of poultry litter.

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