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Ammonia Volatilization from a Swine Waste Amended Bermudagrass Pasture

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ABSTRACT

Ammonia (NH_3) volatilization may be an important part of the nitrogen (N) budget in swine-waste-amended farming systems. Ammonia volatilization was quantified from three circular bermudagrass (*Cynodon dactylon*, [L.] *pers*) plots receiving three split swine (*Sus scrofa* domestica) effluent applications during the 1998, 1999, and 2000 growing seasons. Plots were maintained over the course of the study and used to characterize relative volatilization patterns following land-application of effluent. Swine effluent was applied based on total phosphorus concentration to approximate $9\,kg\,ha^{-1}\,application^{-1}$. Based on the total amount of N supplied via swine effluent, plots were supplemented with ammonium nitrate to meet bermudagrass N requirements of $112\,kg\,ha^{-1}\,application^{-1}$. Immediately following waste treatments NH_3 volatilization rates were quantified using a passive field scale

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technique, which consisted of a rotating mast and five oxalic acid charged tubes located at the center of each plot. Peak volatilization rates ranged from approximately 3 to 8 kg NH_3 ha^{-1} day^{-1}, and total N losses were between 8 to 31% of N applied as swine effluent supplemented with ammonium nitrate. Ammonia volatilization losses associated with land-applied swine effluent were greatest immediately following application and quickly diminished to background volatilization rates.

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INTRODUCTION

Animal manure offers an economical source of plant nutrients, and continues to be a major component of agricultural byproducts. Swine production in the U.S. approaches 60,000 head valued at $76/head.[1] Currently, southeastern states account for 18% of total swine production, with Alabama accounting for 3.6%.[1] Annual production of swine manure in the U.S. is approximately 115 billion kg yr^{-1} based on average daily excretion of a 90 kg hog.[2] Mismanagement of swine waste could lead to substantial gaseous N losses prior to plant uptake. Thus, consideration should be given to management of swine waste as it relates to atmospheric trace gases such as NH_3.

A substantial portion of N in swine effluent consists of NH_4-N. Volatilized NH_3-N leads to aerosol formation of complex sulfates, and contributes to smog and acid rain formation.[3,4] Rates of NH_3-N volatilization are a function of chemical reaction rates and diffusive and convective transport around the waste surface, which are in turn influenced by temperature, evapotranspiration, concentration of gas at the waste surface, and water content.[5] Volatilization rates following application of swine effluent increase with temperature, and also increase linearly with dry matter content.[6,7] Absorption and desorption of NH_3-N in the liquid phase depends heavily on pH. Decreasing pH values are indicative of ongoing volatilization, as protons are released during this process, and typically occur within one day of waste application.[7–9] As soil pH decreases, NH_3-N volatilization slows due to proton activity.

Moal et al.[6] found that up to 63% of total NH_3-N applied as swine effluent was lost via volatilization subsequent to effluent applications to grass, whereas only 37 to 45% of total NH_4-N in waste was lost if applied to wheat stubble. Effluent attached to grasses increases potential volatilization rates by inhibiting effluent infiltration into the soil. Pain et al.[9] documented volatilization rates in grassland fertilized with 160 kg N ha^{-1} from swine effluent. Volatilization losses observed were as low as 5 to 27% of total NH_4-N, of which 24 to 39% occurred within 1 hour and 85% within 12 hours. In a similar study conducted by Jarvis and Pain,[10] losses were similar to those previously reported,[10] with greater than 90% of total losses sustained within 5 days of treatment. Jarvis and Pain[10] also showed that elevated levels of solids may inhibit infiltration and promote volatilization. Volatilization rates vary among swine effluent applications, but most studies show a diurnal pattern of volatilization, peaking with maximum daily temperatures at midday.[6,7,9,11] Moal et al.[6] reported as much as 83% loss of total NH_4-N within 6 hours following a midday effluent application, compared to a 42% loss following an evening application.

Most research in this area has been conducted in laboratories or closed field experiments. Information obtained from such experiments is often difficult to apply to field situations because partially or totally enclosed systems promote transport rates that are likely different from those in open, natural environments. The objective of this study was to determine NH_3-N volatilization rates and to quantify total volatilization losses from swine effluent applied to established bermudagrass pastures with a field-scale technique.

MATERIALS AND METHODS

Ammonia volatilization was evaluated from three circular 0.115 ha bermudagrass plots. Plots were established and maintained at a site north of Auburn, AL (32.41° N, 85.30° W), on a Hiwassee sandy loam (fine, kaolinitic, thermic Typic Rhodudults), having a surface soil (0–20 cm) pH of 6.4. The study began in the spring of 1998 and was repeated in 1999 and 2000. Each year plots received three split applications of swine effluent determined via total P content with a target rate of $9.2\,kg\,P\,ha^{-1}\,application^{-1}$. Based on total N applied as swine effluent, supplemental ammonium nitrate was applied to meet crop N requirements of $112\,kg\,N\,ha^{-1}\,application^{-1}$ immediately following effluent application. Due to limited effluent storage units in 1998, each application took place over a series of days. Additional storage tanks acquired during the 1999 and 2000 growing season facilitated the effluent application process. Monthly precipitation and average temperature during NH_3 volatilization measurement periods are shown in Table 1.

The experiment was designed as a measurement of phenomena (NH_3 volatilization) on three identically treated plots, and did not lend itself to analysis of variance. Volatilization rates presented represent the total NH_3

Table 1. Average monthly precipitation and temperature during application months at the study site north of Auburn, AL.

Date	Precipitation (mm)	Temperature (°C)
May-98	41	23
July-98	96	28
August-98	29	27
April-99	37	18
July-99	55	26
September-99	87	18
April-00	71	15
June-00	64	25
September-00	1077	21

volatilized, as background emissions were subtracted. Standard error of means are provided to indicate variability among applications each year.

Swine effluent was taken from the primary lagoon at the Swine Nutrition Unit at Auburn University. The Swine Nutrition Unit is a 60 sow farrow to finish unit. Swine waste handling consisted of flushing the farrow unit with recirculated effluent and redelivery to the lagoon for storage. Effluent used for land-application was pumped from the primary lagoon at 46 cm below the lagoon surface, avoiding bottom sludge. In the field, a sprinkler system applied an even distribution of effluent during each treatment period. Bermudagrass on the plots was cut to 10 cm height and removed prior to each application.

Swine effluent characterization consisted of pH, NH_4-N, NO_3-N, total P, total N, and total suspended solids concentration (Table 2). Nitrate and NH_4-N concentrations were determined colorimetrically.[12] Total N was quantified via distillation (Tecator Model 1030 Auto Analyzer) following sulfuric acid dilution and digestion at 400°C according the procedures given by Cleseri et al.[13] Prior to determining P content via inductively coupled plasma spectroscopy, swine waste was digested with a 70:30 nitric to perchloric acid mixture at 200°C.[14] Total suspended solids were determined using the procedure of Cleseri et al.[15] Waste pH was determined with a pH meter and a glass electrode.

Ammonia volatilization was measured with a passive field scale technique.[16] This method consists of a single rotating mast 3-m in height equipped with five, 20-cm long, oxalic acid-charged glass tubes at heights of 40, 70, 150, 220, and 300 cm. A wind vane atop each mast ensures the glass tubes always face the prevailing wind. Air flows through the oxalic acid

Table 2. Nitrogen, P, and pH of swine effluent applied at the study site north of Auburn, AL. Total N refers to the amount of N applied via swine effluent. NH_4-NO_3 represents the supplemental commercial fertilizer, and values in parenthesis indicate standard deviation.

Date	Total N ($kg\,ha^{-1}$)	NH_4-NO_3 ($kg\,ha^{-1}$)	NH_4-N ($kg\,ha^{-1}$)	NO_3-N ($kg\,ha^{-1}$)	P ($kg\,ha^{-1}$)	pH
May-98	59(6)	53	42.9(5.2)	9.9(4.7)	17.5(4.2)	7.64(0.07)
July-98	112(6)	0	78.9(5.2)	22.2(15.2)	38.4(4.0)	8.33(0.07)
August-98	47(7)	65	31(4.7)	9.9(22.7)	15.3(2.2)	8.43(0.07)
April-99	42(7)	77	11.8(0.3)	5.1(1.2)	6.4(1.0)	8.05(0.07)
July-99	43(9)	49	11.4(1.6)	2.2(.5)	9.8(2.1)	8.16(0.24)
September-99	62(9)	61	16.5(1.6)	2.8(.5)	16.1(3.6)	8.34(0.03)
April-00	52(2)	59	3.3(1.4)	17.7(2.9)	13.0(2.4)	9.17(0.10)
June-00	23(5)	89	5.4(0.9)	4.8(1.)	7.0(0.7)	8.22(0.10)
September-00	37(9)	84	10.7(1.9)	11.1(3.6)	11.8(2.1)	8.09(0.10)

charged tubes trapping any NH_3 present. Ammonia volatilization masts were placed at the center of each plot, and a separate mast was placed upwind of plots to determine background volatilization rates. Daily volatilization measurements began immediately following swine effluent application and continued for approximately two weeks. Ammonia was extracted from each tube with deionized water and measured colorimetrically.[12] Total NH_3 volatilized from swine effluent amended plots was quantified by subtracting background emissions. Next, vertical flux of NH_3-N was determined by summing the horizontal flux of NH_3-N at each measurement height.[16,17]

RESULTS AND DISCUSSION

Approximately 60% of total NH_3 volatilization took place within 4 days of application (Figs. 1–3). Furthermore, results from 1999 and 2000 show that 80% of total volatilization took place four to six days after application. In 1999 and 2000 all swine effluent was applied over the course of a single day compared to a two to three day application time in 1998. Due to the prolonged application period in 1998, 80% of total NH_3-N losses did not occur until day ten (Figs. 1–3). In all cases, volatilization rates peaked immediately following application of swine effluent, and rapidly declined to background emissions four to six days following treatment (Fig. 4). Peak rates ranged from 3.0 to 4.2 kg of NH_3-N $ha^{-1}\,day^{-1}$ in 1998, 4.0 to 7.0 kg of NH_3-N $ha^{-1}\,day^{-1}$ in

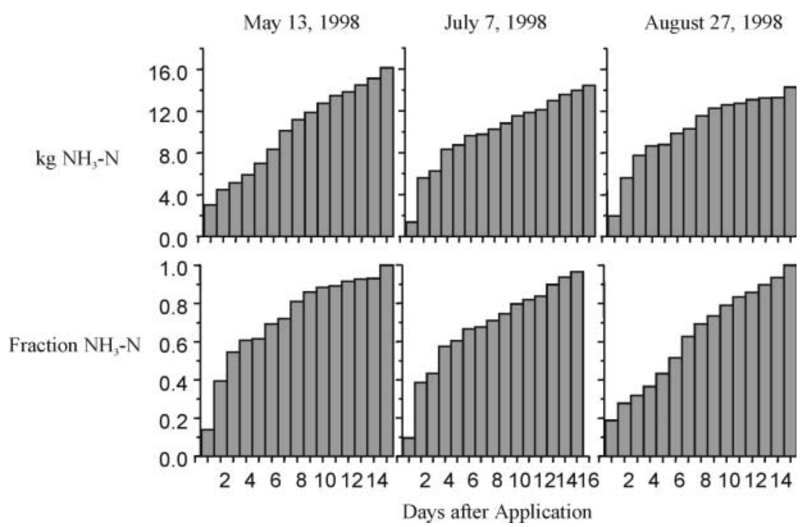

Figure 1. Cumulative daily ammonia volatilization mass loss and cumulative loss expressed as a fraction of total volatilization at the study site north of Auburn, AL, during the 1998 growing season.

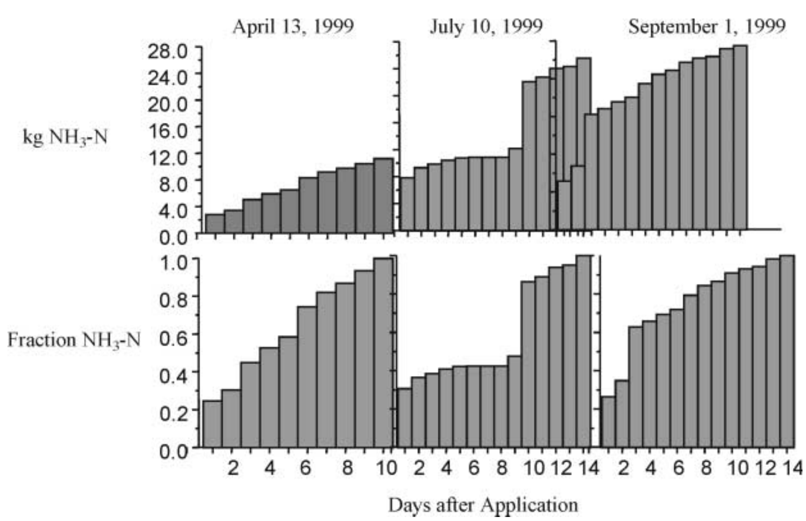

Figure 2. Cumulative daily ammonia volatilization mass loss and cumulative loss expressed as a fraction of total volatilization at the study site North of Auburn, AL, during the 1999 growing season.

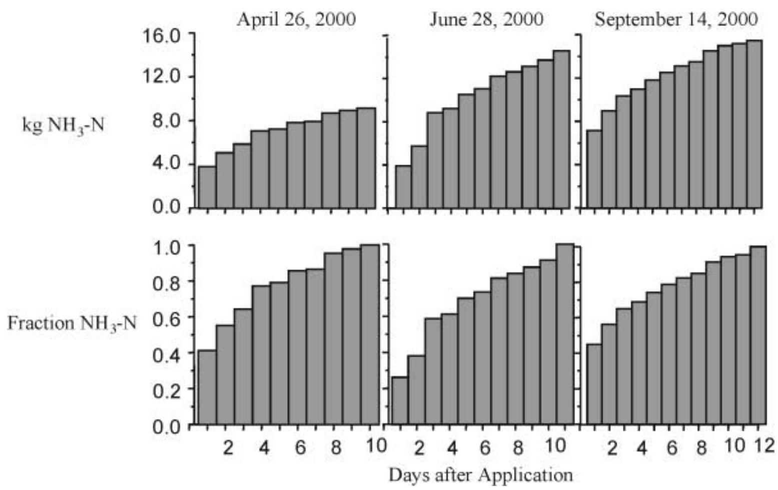

Figure 3. Cumulative daily ammonia volatilization mass loss and cumulative loss expressed as a fraction of total volatilization at the study site North of Auburn, AL, during the 2000 growing season.

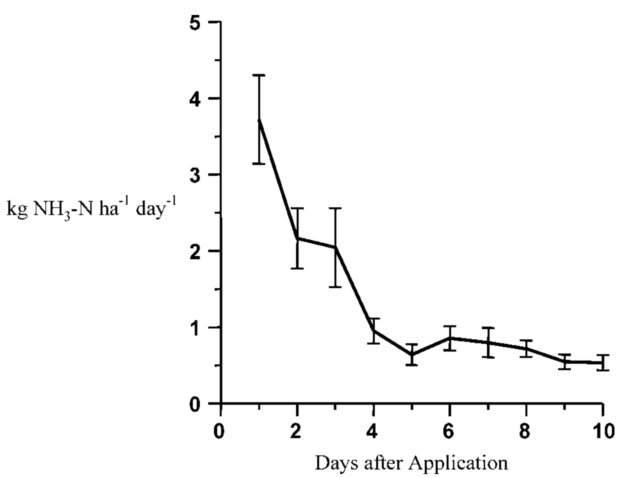

Figure 4. Typical pattern of ammoniacal N loss via volatilization during swine effluent application at the study site north of Auburn, AL. Data represents an average loss per day over all applications. Bars indicate standard error.

1999, and 3.0 to 8.0 kg of NH_3-N ha^{-1} day^{-1} in 2000. Differences in peak rates from year to year likely reflect differences in climate, waste pH, and degree of grass stubble present from year to year. Several studies report similar findings of volatilization rates increasing initially with a rapid decline to background emissions over approximately 10 days.[18−21] In a recent study, Marshall et al.[18] found that volatilization rates peaked within 4 days of poultry litter application supplying 70 kg N ha^{-1} to a tall fescue (*Festuca arundinacea* Schreb.) pasture and reached background levels by the tenth day. Similarly, Sommer et al.[7] found that greater than half of all NH_3-N losses during a 6 day period took place within 24 hours of application following cattle effluent amendments to a sandy loam soil.

Total N losses via volatilization over the three year study period ranged from 9 to 18 kg N ha^{-1} over applications during the course of study (Table 3). Total N losses approached and, in some cases exceeded suggested tolerable atmospheric loading rates of 10 to15 kg N ha^{-1} yr^{-1} based on reports from a workshop in Sweden on critical N loading from grassland emissions in Europe.[22] Nitrogen losses from swine effluent ranged from 13 to 16%, 27 to 31%, and 8 to 15% during the 1998, 1999, and 2000 study periods, respectively. Some differences were observed between applications each year owing to quality of bermudagrass stand or grass clippings present slowing swine effluent infiltration, swine effluent pH, rainfall, and temperature. Results correspond well with previous reports of N loss as a percentage of total N applied as animal waste. Whitehead and Raistrick[23] found that 7 to 41% of N applied as cattle urine volatilized over a 10-day period under laboratory

Table 3. Nitrogen losses due to volatilization at the study site north of Auburn, AL. Percentage of total N represents losses of total N applied as swine effluent. Values in parentheses are standard errors (n = 3).

Date	Total N (kg ha^{-1})	Total N (%)	NH_4-N (%)
May-98	16.2(3.9)	16.1(0.0)	29.9(0.0)
July-98	14.5(4.4)	13.1(0.1)	18.8(0.0)
August-98	14.3(3.7)	13.5(0.1)	45.9(0.0)
April-99	11.2(2.2)	26.6(3.2)	56.4(6.3)
July-99	13.2(3.)	30.5(2.4)	69(4.6)
September-99	17.7(1.7)	28.7(2.7)	67.5(9.7)
April-00	9.1(0.2)	7.9(0.1)	171.7(32.7)
June-00	15.1(0.2)	13.9(0.0)	156.4(9.3)
September-00	15.9(0.4)	15.3(1.2)	97(7.3)

conditions. In another study using a micrometeorological mass balance method, application of swine and cattle manures resulted in 5 to 27% of total N volatilized following application to grassland.[9]

Although volatilization losses reported as a percentage of NH_4-N may be more informative, in our study it was difficult to delineate swine-effluent-applied NH_4-N from commercially applied NH_4-N. Ammonium lost as a percentage of swine effluent applied NH_4-N was variable ranging from 19 to 46% in 1998, 56 to 69% in 1999, and 97 to 172% in 2000. Results suggest that organic forms of N present in swine effluent may be readily converted to NH_4-N, or swine effluent contributed to the volatility of commercially applied forms of N as evidenced in year 2000 (Table 3). Ammonium nitrate pellets are water soluble, and when used alone are not generally susceptible to volatilization. Many studies report similar observations of NH_4-N losses from land-applied animal wastes as high as 36 to 78%.[8,9,19,24] For example, Moal et al.[6] found that 45 to 63 % of NH_4-N was lost following land application of swine effluent to grassland. Losses were attributed to decreased effluent infiltration rates due to grasses present. Comparable NH_4-N losses were also reported by Lockyer,[19] with 36 to 78% of NH_4-N volatilized within 5 days.

Strategies to minimize volatilization losses of N include efficient N utilization based on crop requirements[25] and split fertilizer applications to alleviate unnecessary N losses.[25,26] Swine waste infiltration rates also influence NH_3 volatilization losses, thus incorporation of swine waste into soil may reduce the potential for volatilization.[6] Keeping in mind that volatilization losses are greatest during hot, dry, windy conditions within 4 days of treatment, timing applications to avoid prime volatilization conditions may restrict gaseous N losses.

CONCLUSIONS

Ammonia volatilization rates peaked quickly subsequent to applications of swine effluent supplemented with commercial fertilizer to bermudagrass pasture. Observations of increased volatilization were consistent among applications and years. Despite difficulty in distinguishing between NH_4-N lost as applied swine effluent or ammonium-nitrate, it appears, based on swine effluent applied NH_4-N, that swine effluent may promote volatilization of commercial sources of N, that organic N sources readily convert to NH_4-N upon land-application, or that both actions contribute to N loss. Over a three-year treatment period total N losses ranged from 8 to 31% of swine effluent applied N with peak volatilization rates ranging from 3 to 8 kg NH_3-N ha^{-1} day^{-1}. Results indicate environmental conditions and effluent characteristics at the time of land-application play an important role in NH_3 volatilization rates and in efficient N management strategies in swine-effluent-amended bermudagrass systems.

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