
TECHNICAL REPORTS

Atmospheric Pollutants and Trace Gases

Ammonia Volatilization from Surface-Applied Poultry Litter under Conservation Tillage Management Practices

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ABSTRACT

Land application of poultry litter can provide essential plant nutrients for crop production, but ammonia (NH₃) volatilization from the litter can be detrimental to the environment. A multiseason study was conducted to quantify NH₃ volatilization rates from surface-applied poultry litter under no-till and paraplowed conservation tillage managements. Litter was applied to supply 90 to 140 kg N ha⁻¹. Evaluation of NH₃ volatilization was determined using gas concentrations and the flux-gradient gas transport technique using the momentum balance transport coefficient. Ammonia fluxes ranged from 3.3 to 24% of the total N applied during the winter and summer, respectively. Ammonia volatilization was rapid immediately after litter application and stopped within 7 to 8 d. Precipitation of 17 mm essentially halted volatilization, probably by transporting litter N into the soil matrix. Application of poultry to conservation-tilled cropland immediately before rainfall events would reduce N losses to the atmosphere but could also increase NO₃ leaching and runoff to streams and rivers.

THE USE OF poultry manure as a source of nutrients for crop production is a common practice in the southeastern United States and land application has been the preferred method of manure management. In 1998, the U.S. poultry industry produced almost eight billion broilers (Georgia Agricultural Statistics Service, 1999). At a total production rate of 1.46 kg litter per bird, these broilers generated almost 12 million Mg of litter, a mixture of bird excreta, feathers, waste feed, and bedding material. Application of organic waste materials on agricultural land has received considerable attention in recent years because of potential environmental problems such as water quality degradation, air pollution through N gas emissions, odors, and dispersal of pathogenic organisms (Edwards and Daniel, 1992; Chadwick et al., 2000; Barton and Schipper, 2001).

Ammonia is the primary neutralizing agent for atmospheric acids and is a common component of atmospheric aerosols such as ammonium sulfate [(NH₄)₂SO₄] and ammonium nitrate (NH₄NO₃). These compounds

are important factors in acid rain and when leached by rain to the soil are rapidly oxidized to nitric and sulfuric acid (van Breemen et al., 1982). Atmospheric NH₃ is produced from decomposing feces and hydrolysis of urea in urine to NH₄. These losses occur during animal production and application of the manure as fertilizers, and losses from burning biomass. There is a growing realization of the importance of NH₃ emissions and their role in acidification and eutrophication of terrestrial ecosystems. Natural ecosystems are thought to be net sinks for NH₃ (Denmead et al., 1976; Van Hove et al., 1987) since most of these systems are N deficient. Forests may be sinks or sources for atmospheric NH₃ depending on atmospheric concentrations. Langford and Fehsenfeld (1992) showed that a montane-subalpine forest was a NH₃ source when exposed to low atmospheric concentrations of NH₃ but a sink when exposed to air enriched from agriculture sources. Ammonia emitted from agricultural sources has been implicated in forest decline (McLeod et al., 1990; Nihlgard, 1985) and species changes in the heathlands of Europe (Van Hove et al., 1987). Several studies have shown that agricultural crops can both absorb and emit NH₃ depending on their N status and atmospheric concentrations of NH₃ (Sharpe et al., 1988; Harper and Sharpe, 1995).

Methodology exerts a strong influence on the magnitude of NH₃ losses measured (Terman, 1979; Harper, 2004). Laboratory techniques usually show greater losses than field techniques (Schilke-Gartley and Sims, 1993) and dynamic techniques also tend to show greater losses than static techniques because of the influence of NH₃ gradients and turbulence (Harper, 1988). Ammonia volatilization rates in laboratory and dynamic flow-through chamber studies have ranged from 4 to 60% of the total N applied depending on fraction size of litter and soil moisture (Lockyer et al., 1989; Brinson et al., 1994; Cabrera et al., 1994). Open-field studies in contrast have shown losses of less than 7% of the total N applied in poultry litter (Nathan and Malzer, 1994; Marshall et al., 1998). Noninterference, open-field studies often show dynamic differences when compared with chamber studies because chamber techniques influence

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Abbreviations: DOY, day of year; NT, no-till; PP, paraplowed.

the physical and chemical properties responsible for NH_3 emissions (Harper, 2004).

Conservation tillage systems have been widely adopted in the Southern Piedmont of the United States because they reduce soil erosion and increase water retention (Langdale et al., 1979; Reicosky et al., 1977). The use of conservation tillage management mandates surface application of poultry litter, which may increase NH_3 volatilization losses. Most of the studies concerning NH_3 volatilization from poultry litter have been laboratory studies with few open-field studies. The scarcity of field studies, influence of methodology on the magnitude of NH_3 measurements, and the potential environmental impact of surface application of poultry litter indicate that the need exists to quantify NH_3 fluxes. Our objective was to quantify gaseous losses of NH_3 after surface application of noncomposted poultry litter under conservation tillage management.

MATERIALS AND METHODS

This research was conducted on two paired water catchments in Watkinsville, Georgia (33°56' N, 83°19' W), on Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludult) soils (Fig. 1). Before this study both catchments were managed for at least 10 yr with no-tillage. One catchment (NT) was 1.3 ha and the other catchment (PP) was 1.4 ha. The two catchments were immediately adjacent to each other. Both catchments were managed the same except one catchment (PP) was paraplowed to a depth of 30 to 40 cm each fall starting in 1999. The paraplow is a deep-tillage instrument used to loosen soil without inversion and with minimal disturbance of surface residues. Summer crops were pearl millet (*Pennisetum glaucum* L.) in 2000 and grain sorghum [*Sorghum bicolor* (L.) Moench] in 2001. Winter crops were rye (*Secale cereale* L.) in the winter of 2001–2002. Crops were fertilized with inorganic P and K and with broiler litter in July 2000 and 2001 and in December 2001. The goal was to apply equal amounts of total N to each catchment, but PP catchment received more N than the NT catchment in each application (Table 1). Poultry litter was applied immediately after planting before seed germination. The standing stubble from the previous crop was 10 to 15 cm tall. Application rates, total Kjeldahl nitrogen, NH_4 , and NO_3 content for each application are shown in Table 1. Total N content of the litter was determined by dry combustion with a C and N analyzer (Nelson and Sommers, 1982). Inorganic N was determined by steam distillation (Keeney and Nelson, 1982).

Micrometeorological instruments were located near the center of the field to obtain a minimum fetch of 50:1 (upwind canopy distance to measurement height) in all directions for

wind profile development. Micrometeorological data and atmospheric NH_3 concentrations were determined 24 to 48 h before litter application and for 7 to 8 d following applications. Wind speed (sensitive cup anemometers, Model 106-LED-DC; Thornthwaite Assoc., Pittsgrove, NJ) and air temperature (aspirated thermocouples, Model ASPTC; Campbell Scientific, Logan, UT) profiles were measured at six heights (plant height plus 0.2, 0.4, 0.6, 0.8, 1.6, and 2.7 m). During the summer 2000 study, atmospheric concentrations of NH_3 were measured at plant height plus 0.6 and 1.6 m using tunable diode laser (TDL) spectroscopy. The TDL (Model TGA100, Campbell Scientific) technique is based on infrared spectroscopy (Warland et al., 2001; Edwards et al., 1994). The diode laser is mounted in a liquid nitrogen-cooled dewar and a heater in the dewar gives precise control of the laser in the 78- to 110-K region. The laser was operated in the IR spectral region between 1700 and 1800 cm^{-1} . The sample and reference cells are 1.54 and 0.05 m long, respectively. Both sample and reference detectors were Peltier-cooled mercury-cadmium-tellurium IR detectors (EG&G; Judson, Montgomeryville, PA). The instrument had a short-term (sample period) total noise of about 10 ppbv. The TDL's electronics were integrated with a PC for software control of the digital signal processing, laser function, real-time display of laser-operating functions, and for data storage. The TDL was located in a small trailer at the edge of the field about 65 m from the air intake points. Atmospheric samples were drawn through a 1.27-cm-i.d. low density polyethylene tube and atmospheric gas concentrations were measured 10 times per second. Switching time between heights was 3 min and switching time between fields was 15 min. A switching time of 3 min allowed sufficient time for laser NH_3 concentration readings to stabilize at any given height. Each sampling port in both fields was exposed to known concentrations of reference gases to ensure that the switching times between fields and between heights in a field were correctly set. Delta concentrations were averaged over 30-min periods for use in the flux gradient technique. During the 2001–2002 studies, NH_3 concentration profiles were measured at 0.2, 0.4, 0.6, 0.8, 1.6, and 2.7 m above plant height. Ammonia concentrations in air samples were measured by drawing unfiltered air at a rate of 6 L min^{-1} through gas washing bottles containing 80 mL of 0.1 M H_2SO_4 for a period of four hours (Weier et al., 1980). Average flux rates were determined from atmospheric NH_3 concentration profiles and average wind speed and air temperatures during the 4-h period.

Ammonia gas flux densities above the canopy were determined during the measurement seasons using gas concentrations and the flux gradient gas transport technique using the momentum balance transport coefficient. The relationship for gas flux density is:

$$F = K_{mb}(\partial n/\partial z) \quad [1]$$

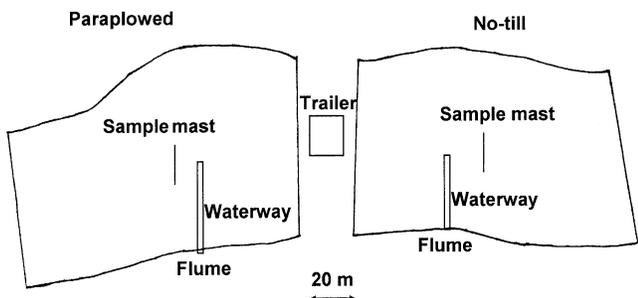


Fig. 1. Field diagram showing location of sampling masts and instrument trailer. The flumes are collection points for sampling runoff.

Table 1. Poultry litter, total N, NH_4 , and NO_3 application rates.

Treatment†	Application Mg ha ⁻¹	kg ha ⁻¹		
		Total N	$\text{NH}_4\text{-N}$	$\text{NO}_3\text{-N}$
		5 July 2000		
NT	3.34	109.2	17.4	0.48
PP	2.73	87.2	10.5	0.48
		2 July 2001		
NT	3.37	98.9	14.8	0.80
PP	2.70	86.9	10.5	0.30
		21 December 2001		
NT	4.65	133.4	40.6	0.87
PP	4.42	138.9	55.0	1.10

† NT, no-till; PP, paraplowed to a depth of 30 to 40 cm.

where F is the gas flux density ($\text{kg NH}_3\text{-N ha}^{-1} \text{d}^{-1}$), n is atmospheric gas concentration ($\mu\text{g NH}_3\text{-N m}^{-3}$), z is gradient measurement height (m), and K_{mb} is eddy diffusivity ($\text{m}^2 \text{s}^{-1}$) for the gas of interest. A negative F value indicates absorption and a positive value indicates emissions from the field. The magnitude of K_{mb} depends on the level of turbulence wind speed, surface roughness, height above ground, and the thermal stability of the atmosphere and can be determined from the relationship:

$$K_{\text{mb}} = \frac{-k^2 (u_2 - u_1)}{\{\ln[(z_2 - z_d)/(z_1 - z_d)] - [\Psi(z_2 - z_d) - \Psi(z_1 - z_d)]\}^2} \quad [2]$$

where k is the von Karman constant (0.41), u is wind speed (m s^{-1}) at upper height (u_2) and lower height (u_1), z_d is effective vegetation height (m), and Ψ is the stability correction factor (Dyer and Hicks, 1970). Errors associated with the flux-gradient gas transport technique have been discussed by Harper (1988) and Denmead and Raupach (1993) and error attributed to the technique is $\pm 15\%$. Effective vegetation height was calculated from wind speed profiles using a modification of the least square technique described by Wright and Lemon (1966).

RESULTS AND DISCUSSION

Total N in the litter used in these studies ranged from 0.27 to 0.44 g kg^{-1} (dry weight basis), which was within

the range of 0.14 to 0.68 g kg^{-1} reported by Overcash et al. (1983) from a compilation of more than 30 studies involving poultry litter. Inorganic N levels, primarily NH_4 , ranged from 0.03 to 0.17 g kg^{-1} with the litter containing the highest concentrations being applied during winter 2002. This resulted in an application of 2.5 to 5 times more NH_4 during the winter than the summer studies even though total N applications were only about 30% greater (Table 1). There was a small influx of NH_3 before the summer 2000 litter application (Fig. 2) but there was little or no flux into or out of the systems before the summer 2001 or winter studies (Fig. 3 and 4).

In all three studies, there was a rapid increase in NH_3 volatilization immediately following application. The greatest volatilization rate, about 27 $\text{kg NH}_3 \text{ha}^{-1} \text{d}^{-1}$, occurred on day of year (DOY) 188 during the summer 2000 study (Fig. 2). The much greater volatilization from the NT than PP fields was due to the differences in NH_4 applications. About 50% more readily volatilizable NH_4 was applied to the NT than PP field (17.4 and 10.5 $\text{kg NH}_3 \text{ha}^{-1}$, respectively). Volatilization rates gradually decreased from DOY 188 to 193 with little or no NH_3 loss after 20 mm of rain on DOY 193. The rain probably transported most of the readily soluble N into the soil

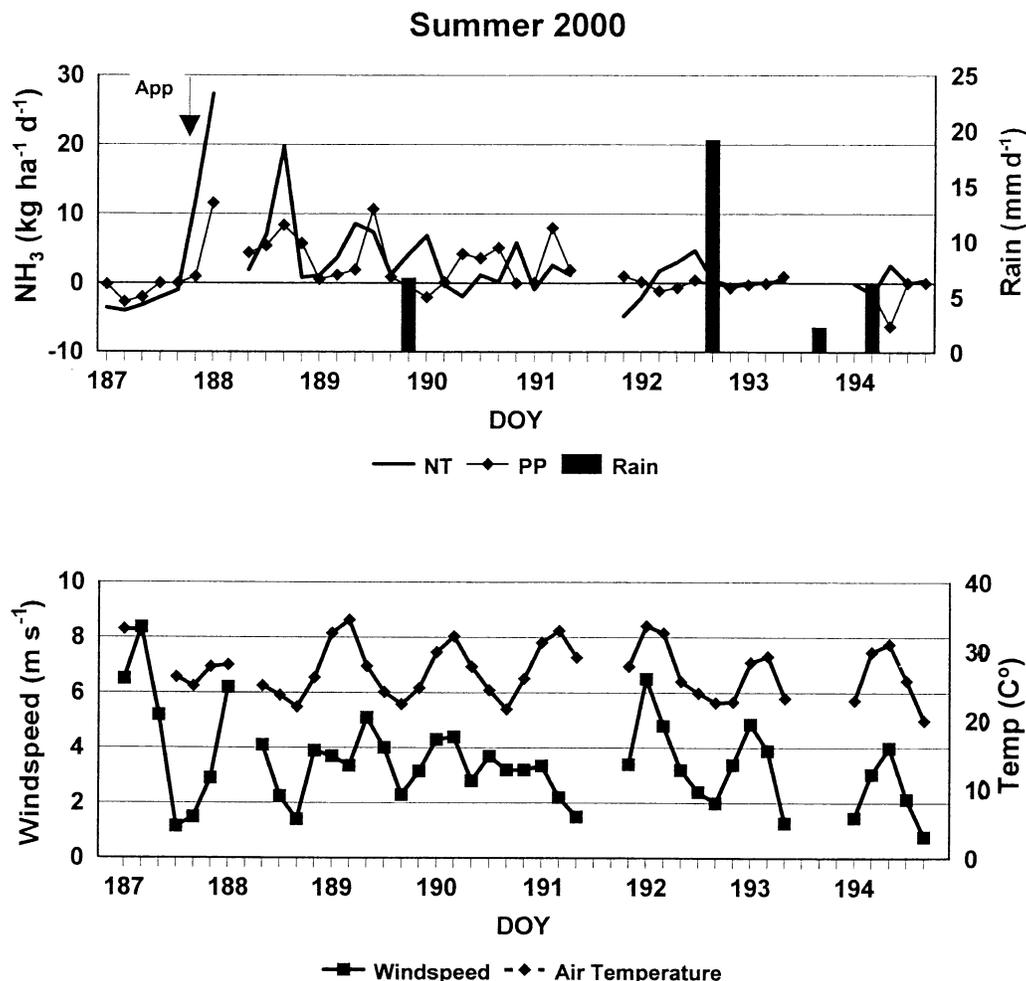


Fig. 2. Ammonia volatilization rates, rainfall, wind speed, and temperature during the summer of 2000. Wind speed and air temperature were measured 1.7 m above the soil surface. DOY, day of year; NT, no-till; PP, paraplowed.

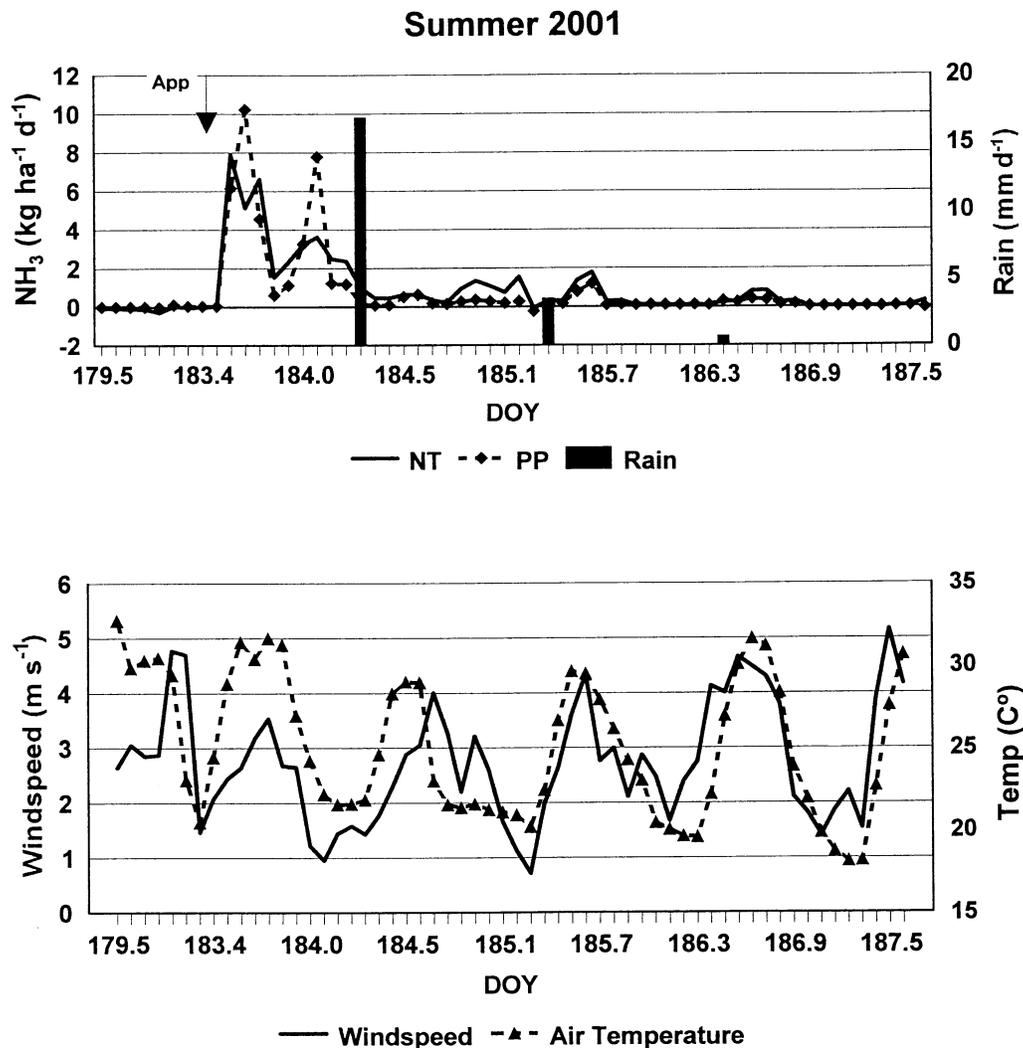


Fig. 3. Ammonia volatilization rates, rainfall, wind speed, and temperature during the summer of 2001. Wind speed and air temperature were measured 1.7 m above the soil surface. DOY, day of year; NT, no-till; PP, paraplowed.

matrix and several studies have shown that incorporation of animal manures into the soil greatly reduces NH_3 volatilization (Adamsen and Sabey, 1987; Moore et al., 1995; Cabrera and Vervoort, 1998).

Similar trends occurred during the summer 2001 study, with the greatest volatilization in the first 48 h after application followed by a rapid decrease in volatilization after a rainfall (Fig. 3). During the first 48 h after application, total NH_3 losses were 5.8 and 5.6 $\text{kg NH}_3 \text{ ha}^{-1}$ for the NT and PP fields, respectively, which would correspond to the greater N application to the NT field. Ammonia volatilization rates were much less in summer 2001 than summer 2000, especially in the NT field. This was probably due to the lower N application rates in 2001 (Table 1) and to the climatic conditions following application. Ammonia volatilization rates are significantly correlated to air temperature and wind speed (Harper and Sharpe, 1995). In these studies, air temperature was about 5°C warmer and wind speed was about twice as great following application in 2000 than in 2001, which would result in greater NH_3 losses.

Ammonia volatilization rates decreased significantly

after the 17 mm of rain on DOY 184 (Fig. 3). This is in contrast to the Cabrera and Vervoort (1998) study, which found that addition of 40 mm of simulated rain decreased NH_3 losses, but the addition of 20 mm temporarily increased NH_3 volatilization due to the stimulation of litter decomposition. In this study, 17 mm of rain significantly reduced NH_3 volatilization. The differences between the studies may have been due to differences in poultry litter and experimental conditions. The Cabrera and Vervoort (1998) study used poultry litter that had been passed through a 2-mm sieve to remove large particles, which would increase surface area and litter decomposition. Also, the litter used in the Cabrera and Vervoort (1998) study contained a higher percentage of total N and $\text{NH}_4\text{-N}$ and treated soil columns were stored under conditions that maximized NH_3 losses to the atmosphere.

In the winter 2001–2002 study, NH_3 losses occurred primarily during the warmest part of the day with little or no volatilization during the cold nighttime temperatures (Fig. 4). Maximum volatilization rates of about 10 $\text{kg NH}_3 \text{ ha}^{-1} \text{ d}^{-1}$ were about the same as during the

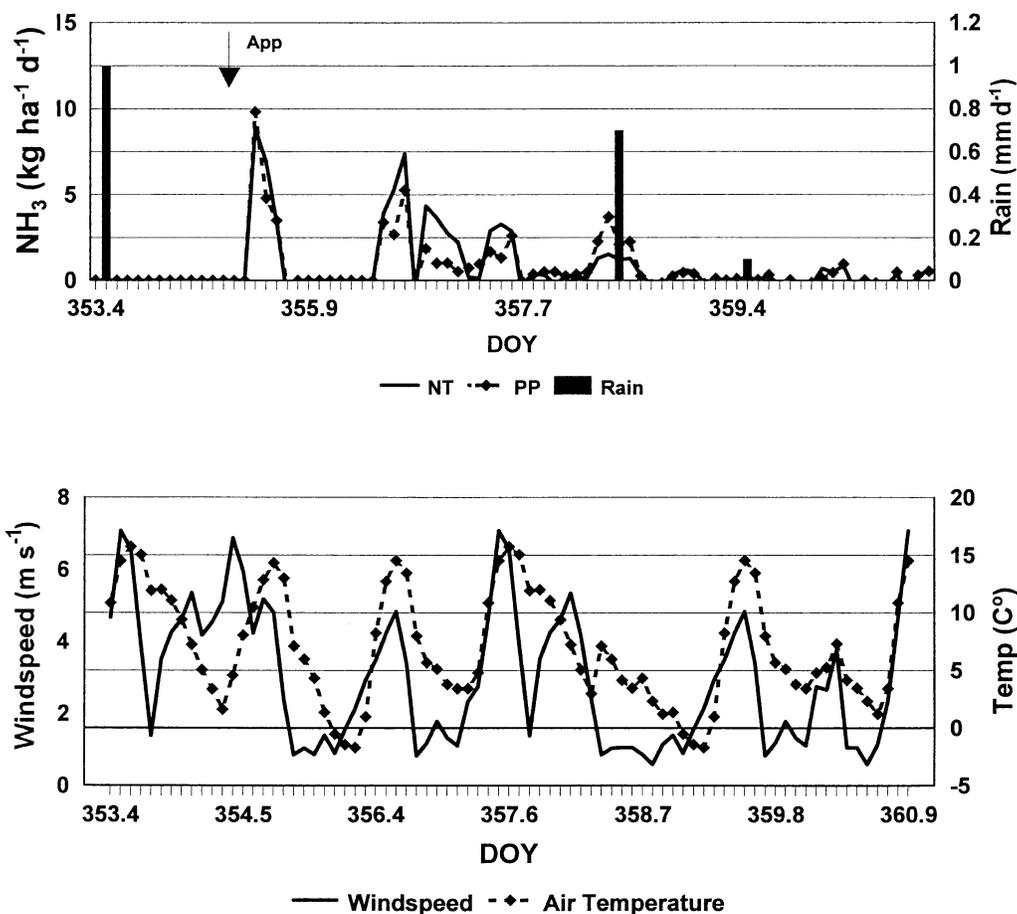


Fig. 4. Ammonia volatilization rates, rainfall, wind speed, and temperature during the winter of 2001–2002. Wind speed and air temperature were measured 1.7 m above the soil surface. DOY, day of year; NT, no-till; PP, paraplowed.

summer 2001 study although total N and NH₄ in the applications were much greater in the winter study. Wind speed was also greater during the winter study.

Total amount of NH₃-N volatilized, expressed as a percentage of total N and NH₄-N applied, is shown in Table 2. Ammonia losses in the summer 2000 study were slightly greater than those reported by Lockyer et al. (1989) for poultry litter using a dynamic flow-through chamber in the field but three times greater than that reported by Marshall et al. (1998) for open-field studies in the southeastern United States. The lower NH₃ losses in the Marshall et al. (1998) study may have been due to the presence of an actively growing crop or to climatological differences in the studies. In the Marshall et al. (1998) study there was a dense, actively growing crop that could have absorbed some of the atmospheric NH₃ (Denmead et al., 1976). This study was conducted under conditions of high humidity, heavy dews, and high soil moisture, which they postulated could have reduced NH₃ volatilization. In the summer 2000 study, the poultry litter was applied to a dry soil (<0.1 cm³ cm⁻³) during a period of high temperature and high wind speed (Fig. 3), all of which would tend to maximize NH₃ volatilization (Lockyer et al., 1989; Nathan and Malzer, 1994). Most of the NH₃ was volatilized within 72 h after application. The additional losses of NH₃ (Table 2) were probably

due to mineralization of organic N at the soil surface and the subsequent volatilization of NH₃. Losses during the winter study were less than either of the summer studies, especially when expressed as the percentage of NH₄ lost. This is in agreement with other studies showing decreased volatilization rates in winter (Lauer et al., 1976) due to decreased chemical and biological reactions during low temperatures.

CONCLUSIONS

Total losses of NH₃ from surface-applied poultry litter ranged from 3.3 to 24% of the total N applied with the largest losses under hot, dry, windy conditions. Losses of 22 to 24% as in the summer 2000 study would be large enough to potentially decrease crop yields when

Table 2. Total NH₃-N losses expressed as a percentage of total N and NH₄-N applied.

Season	NT†		PP†	
	Percent of total N	Percent of NH ₄ -N	Percent of total N	Percent of NH ₄ -N
Summer 2000	23.9	95.1	22.3	101.0
Summer 2001	5.4	36.3	5.2	42.3
Winter	4.1	13.4	3.3	9.9

† NT, no-till; PP, paraplowed to a depth of 30 to 40 cm.

poultry litter is used as the sole source of N fertilizer and applications are based on the N content of the litter. In addition losses of this magnitude have the potential to affect nearby natural ecosystems. Rainfall within 48 h of application greatly inhibited volatilization rates although 36 to 64% of the NH_4 in the poultry litter was volatilized before precipitation. Application of poultry to conservation tilled cropland immediately before rainfall events would reduce N losses to the atmosphere.

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