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Evaluating runoff water quality and ammonia volatilization in three turkey litter application methods

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Evaluating Runoff Water Quality and Ammonia Volatilization in Three Turkey Litter Application Methods

Michael D. Shamblin

**Thesis submitted to the Davis College of Agriculture, Forestry,
and Consumer Sciences at
West Virginia University
in partial fulfillment of the requirements
for the degree of**

**Master of Science
in
Agriculture and Environmental Education**

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Division of Resource Management

**Morgantown, West Virginia
2002**

**Keywords: Poultry Litter, Manure, Surface Runoff, Nutrient
Management, Surface Banding, Incorporated Banding**

Abstract

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Poultry litter is an important nutrient source in crop production. However, the traditional practice of broadcasting poultry litter on the soil surface could result in nutrient losses in runoff as well as substantial ammonia volatilization losses, which could adversely affect both the environment and agricultural productivity. This research compared nutrient runoff (natural and simulated) losses on 1 m X 2 m plots and ammonia volatilization from different turkey litter application methods (broadcast, surface-banded, incorporated band, and control) applied in triplicate. No significant differences were observed between any of the treatments in any of the runoff constituents measured. Over three runoff events (two simulated) spanning 9 d, ammonium and inorganic phosphorus losses in runoff were substantially lower in the incorporated band treatment than in the broadcast and band applications. Compared with the broadcast and band applications, ammonia volatilization losses from incorporated bands were reduced five-fold over 11 d. Ammonia trapping efficiency of low-cost, passive ammonia samplers were also evaluated. Compared with broadcast application, incorporating surface-banded poultry litter could reduce nutrient losses into the environment which could be particularly useful in conservation tillage.

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Chapter 1

Introduction

The poultry industry in West Virginia is steadily increasing. Poultry production is a major contributor to West Virginia's agricultural sector, producing over half of the total agricultural income. In 2001, poultry production contributed \$143.6 million to West Virginia's economy, up 15% from 2000 (WVASS, 2002). In 2001, US poultry production contributed \$16.7 billion to the economy, up 19% from 2000 (WVASS, 2002). The poultry industry is not only a major contributor to the economy, but is steadily increasing across the country. Commercial poultry production generates large amounts of waste in the form of poultry litter. Poultry litter is a mixture of bedding material, such as, wood chips or shavings or straw, and poultry manure, as well as feathers, feed, and water. In West Virginia, 150,000 to 350,000 tons of poultry litter are produced annually (Ferguson, 1997).

Poultry litter is widely used as a nutrient source for nitrogen (N), phosphorus (P) and potassium (K). One metric ton of poultry litter typically contains 32.5 kg of N, 16.5 kg of P, and 13.5 kg of K. Increases in crop production and soil productivity have been documented with the use of poultry litter (Wood, Wood, Yoo, and Yoon, 1996).

The environmental consequences of livestock production and waste management are of increasing public concern. Over one quarter of US surface water contamination from agriculture has been attributed to livestock waste (Innes, 1999). Nutrients lost through volatilization, runoff, and leaching are areas of concern when land applying poultry litter. Two of the major problems facing the poultry industry with respect to waste management are non-point source P runoff and high levels of atmospheric ammonia (NH₃) (Moore, Daniel, and Edwards, 1999).

Since poultry litter is an inexpensive source of N, it has traditionally been applied based on N content with little regard to P (Gallimore et al., 1999) frequently resulting in over-application of P (Xingguo and Duane, 1996). Corn nutrient requirements are 191 kg of N and 39 kg of P per hectare for 9.8 Mg/ha corn (Tisdale, Nelson, Beaton, and Havlin, 1993). If the N requirement is met with the use of poultry litter, over-application of P by 2.5 times would result, based on N/P ratio in typical poultry litter. Over-application of N and P would be even greater when litter disposal is the primary objective with crop considerations being of secondary importance (Nichols et al., 1994).

Concerns about the amount of P entering aquatic habitats have increased, especially in the eastern U.S. (Hays, 1994). Poultry litter application has been shown to result in high P runoff even when applied at recommended rates (Moore et al., 1999). Over application of P has a negative impact on aquatic habitats since P is the primary limiting agent for freshwater algae and plants in some water bodies. When other environmental conditions (for example, threshold inorganic-N concentrations) are met, P loadings to water bodies can contribute to massive algal blooms (eutrophication), leading to depletion of dissolved oxygen which could result in fish kills.

Nitrogen in poultry litter can supply the crop's N requirement, but can contribute to pollution if lost into the environment. Ammonia volatilization could increase atmospheric levels of N, resulting in increased acid rain (Marshall, Wood, and Guertal, 1998). Ammonia lost through volatilization can be of economic importance because it could lead to substantial losses of N (Cabrera, Chiang, Merka, Thompson, and Pancorbo, 1993).

In order to safeguard both the environment as well as a viable poultry industry, poultry litter management must be a priority. Improved poultry litter application methods could help in

conserving nutrients in the field, and thus, could be an important tool in safeguarding water and air qualities.

1.1 Problem Statement

Broadcasting poultry litter on the soil surface has been a common method of waste management. Ease of disposal and low application costs makes broadcasting the method of choice when applying poultry litter. However, broadcast application may not be the most suitable method for retaining nutrients in the field. Ammonia volatilization can occur more readily under broadcast conditions. Nutrients in the broadcast litter can be carried off in runoff. Alternative methods of application, such as, surface banding (dribbling) have been found to be promising. Bittman, Kowalenko, Hunt and Schmidt (1999) investigated the effects of broadcast and banded liquid dairy manure on tall fescue yields and N uptake. Bittman et. al. (1999) reported that banded application gave higher fescue yields than broadcasting, especially in summer. Bittman et al. (1999) hypothesized that reduced ammonia volatilization due to surface banding could have improved plant yield. Increased plant uptake of N in the banded application could reduce N available for loss and decreases potential environmental degradation.

Phosphorus and N losses can degrade water bodies, reducing productivity and aesthetics. Phosphorus losses in the Potomac River Valley have been blamed for the algal blooms and fish kills in the Potomac River and Chesapeake Bay.

Innovative poultry litter application methods could significantly reduce nutrient losses into the environment. Compared with broadcasting, incorporation of bands could result in reduced nutrient losses in runoff and ammonia volatilization. Hence, banding and incorporated banding of poultry litter could be more suitable for conserving nutrients for crop growth and reducing pollution.

1.2 Objectives of Study

The objective of this study is to evaluate the environmental impacts of different turkey litter application methods (broadcast, band, and incorporated band) through the following specific objectives:

- I. to evaluate the effects of different turkey litter application methods on total runoff volume as well as nitrate-N (NO_3^- -N), ammoniacal-N (NH_4^+ -N + NH_3 -N), total Kjeldahl N (TKN), total P (TP), dissolved reactive P (DRP), sediment bound reactive P (SBRP), and total suspended solids (TSS) concentrations in surface runoff, and,
- II. to evaluate NH_3 volatilization losses from the three turkey litter application methods.

Chapter 2

Review of Literature

Decreasing nutrient loss from agricultural lands is of concern, not only to enhance or maintain crop productivity but also to reduce environmental degradation. When nutrient sources are broadcast on the soil surface, substantial amounts of nutrients can be lost through surface runoff and ammonia volatilization. Selected studies comparing poultry waste application methods with regard to runoff water quality and ammonia volatilization are discussed below.

2.1 Runoff Water Quality Impacts of Poultry Litter Application

Nichols, Daniel, and Edwards (1994) studied the nutrient runoff concentrations in tall fescue after the application of broadcast and broadcast incorporated poultry litter as well as broadcast and broadcast incorporated inorganic fertilizer. Poultry litter and inorganic fertilizer were applied 218 kg N/ha and 87 kg P/ha. In the incorporated plots, poultry litter was tilled into the soil to a depth of 2-3 cm with a rotary tiller. Total Kjeldahl N (TKN), ammoniacal-N, NO_3^- -N, TP, orthophosphate (ortho – P), chemical oxygen demand (COD) and TSS concentrations were examined in runoff. With poultry litter, no significant differences were observed between broadcast and broadcast incorporated treatments. Nichols, Daniel, and Edwards (1994) hypothesized that while deeper incorporation would have damaged the fescue cover, it could have been more effective in retaining nutrients and increasing plant yields.

Edwards and Daniel (1992), surface-applied (broadcasted) poultry manure slurry to grassed areas and examined runoff 1 d after application. Poultry manure slurry was applied at rates of 0, 220, and 879 kg-N/ha to plots with established fescue on Captina silt loam. Rainfall was applied at 5 or 10 cm/h. Runoff samples were analyzed for TKN, NH_3 -N, NO_3^- -N, total P,

DRP, COD, TSS, and electrical conductivity. Slurry application rate had a significant effect on runoff concentrations of all manure constituents except NO_3^- -N. All constituents examined in the study except NO_3^- -N increased linearly with slurry application rate. Mass loss of NO_3^- -N was affected only by rainfall intensity. Edwards and Daniel (1992) concluded that rainfall events occurring soon after surface application of poultry litter produced significantly higher levels of runoff constituents compared with untreated plots.

2.2 Ammonia Volatilization from Poultry Litter Application

Marshal et al. (1998) examined NH_3 volatilization from tall fescue fertilized with broiler litter. Litter was applied at a rate of 70 kg available N/ha. Ammonia was sampled with passive samplers using a micrometeorological mass balance method. Samplers consisted of glass tubes coated with oxalic acid held on 3-m tall masts at central locations on collection plots. Samples were collected on a daily basis for 14 d starting immediately after litter application. Marshal et al. (1998) reported a sharp increase in ammonia volatilization 1-3 d after application, with rates rapidly decreasing to normal levels within 10 d. Marshal et al. (1998) concluded that NH_3 volatilization due to land application of broiler litter was unlikely to cause significant environmental degradation.

Nathan and Malzer (1994) studied the dynamics of NH_3 volatilization from broadcast and incorporated turkey manure. Turkey manure at 16 Mg/ha was surface applied or incorporated immediately with a fork to Estherville sandy loam soil. Soil temperature, air temperature, wind speed, and relative humidity were also measured. Ammonia volatilization was measured using samplers (24 cm diameter PVC cylinders), randomly placed on the plots and pressed 14 cm into the soil. Ammonia samples were taken every 3 h for 20 minutes. Air was drawn from the

sampler using a vacuum pump at -50 kPa and forced into boric acid solution. During times when samples were not taken, the samplers were left uncapped. Nathan and Malzer (1994) concluded that NH_3 losses were 23 times greater for surface-applied manure than for incorporated manure. Positive correlations were seen between NH_3 volatilization and soil temperature, atmospheric temperature, and wind speed. Relative humidity was generally negatively correlated with NH_3 volatilization.

Researchers generally agree that adequate incorporation of nutrients is an important tool in conserving N and P. Broadcast applications are consistently proven to be a less desirable form of application for conserving nutrients. While the environmental impacts of different poultry litter application methods have been evaluated in pastureland, there is need for such a study in conservation tillage corn, particularly because of heavy residue cover and difficulties in incorporating nutrients into the soil. Further research on the environmental impacts of surface banding poultry litter could not be located. Innovative application methods, such as, banding and incorporating bands of poultry litter offer the potential to reduce nutrient losses into the environment, thereby, increasing nutrient availability for crop uptake.

Chapter 3

Materials and Methods

3.1. Field Site and Description

The field site for conducting runoff and ammonia volatilization studies using turkey litter was identified at West Virginia University's Animal and Veterinary Sciences Farm in Morgantown, WV. The field site had been under conservation tillage corn in fall, 2001, that had been followed by wheat as cover crop which had been planted after disking in the winter of 2001-2002. While the main slope of the field site ranged from 8-12%, the cross slope was determined to be less than 2%.

Prior to starting the fieldwork, the wheat cover crop was chemically killed by staff of the West Virginia University Animal and Veterinary Sciences Farm on May 26, 2002. Because of difficulty in conducting fieldwork, the killed cover crop was cut with a sickle bar mower to a height of about 9 cm (3.5 in.) on May 28, 2002, and allowed to dry for 2 days. Upon drying, the wheat crop was raked, baled, and removed from the field site.

3.2. Soil Characteristics

Soil type at the field site was Zoar silt loam (clayey, mixed, mesic, Aquic Hapludults) (SCS, 1982). Zoar silt loam soils are deep, moderately well drained soils formed in acid slackwater deposits of old stream sediments. Zoar soils are typically found along terraces of the Cheat, Monongahela, Tygart Valley, and West Fork Rivers and Dunkard Creek (SCS, 1982). Zoar soils are strongly to very strongly acid. Depth to bedrock on typical Zoar silt loam soil is in excess of 150 cm.

Soil samples were collected at a depth of 5 cm (2 in.), using a tube sampler at multiple points between plots (to avoid disturbing the plots). Samples were frozen prior to analysis. The soil samples were analyzed for selected physical and chemical properties (see Table 3.1).

Table 3.1. Selected Physical and Chemical Properties of the Soil at the Field Site ^[a]

	Sample Mean	Standard Deviation	Method of Analysis
Bulk Density	1.35 g/cm ³	0.03 g/cm ³	Core method
Soil texture	Silt loam		USDA textural triangle
Sand	19.5%	1.9%	Modified pipet
Silt	56.8%	3.0%	
Clay	23.6%	1.3%	
Organic Matter	11.5% ^[b]	0.5%	Loss on Ignition
pH	6.7	0.2	Soil:water::1:1
Total N	0.23% ^[b]	0.02%	Combustion
NH ₄ ⁺ -N	8.8 mg/kg ^[b]	1.0 mg/kg	Titration
NO ₃ ⁻ -N	20.5 mg/kg ^[b]	4.3 mg/kg	Specific ion electrode
TP	67.0 mg/kg ^[b]	49.0 mg/kg	Mehlich 3 extractant
CEC	13.4 meq/100 g ^[b]	1.6 meq/100 g	Summation of cations

^[a] Means based on three samples

^[b] Oven-dry basis

3.3. Treatment Design

There were four treatments: control, broadcast, surface-banded, and incorporated band. The control treatment was added to evaluate runoff water quality and ammonia volatilization in the absence of turkey litter application. Except for the control treatment, all other treatments received turkey litter at a rate of 4500 kg/ha (approx. 2 tons/ac) for both the runoff as well as ammonia volatilization studies. Each treatment was replicated three times in both studies.

3.4. Statistical Methods

For the same runoff or sampling event, pollutant loadings, in kg/ha or g/ha were compared among treatments using Analysis of Variance (ANOVA) (Keppel, 1982) with a level of significance of 5% ($\alpha = 0.05$). For unbalanced data sets General Linear Model (GLM) was used (Keppel, 1982). Fisher's Least Significant Difference (LSD) (Keppel, 1982) was used to make pairwise comparisons ($\alpha = 0.05$). Pair-wise comparisons were made only if the ANOVA p-value was less than α . Statistical Package for the Social Sciences (SPSS) as well as SAS were used for the analysis of data. No statistical analyses were made to compare pollutant concentrations between runoff or sampling events.

3.5. Turkey Litter Characteristics

Dry turkey litter from a plastic covered stack was obtained and stored in sealed containers until time of application. The turkey litter was sieved through 1.3 cm (½ in.) wire mesh before application to remove the large chunks of turkey litter that could have affected uniformity of application. The sieved turkey litter was analyzed for selected physical and chemical properties (see Table 3.2.).

Table 3.2. *Physical and Chemical Properties of the Turkey Litter* ^[a]

	Sample Mean	Standard Deviation	Method of Analysis
Moisture Content	289.7 g/kg	5.2 g/kg	Oven drying
TKN	26.6 g/kg	2.8 g/kg	Titration
Ammoniacal-N	6.3 g/kg	0.0 g/kg	Titration
TP	9.6 g/kg	0.0 g/kg	Mehlich 3 extractant
C:N	11.3	1.3	Calculated
K	18.8 g/kg	0.7 g/kg	Mehlich 3 extractant
pH	8.5	0.0	Electrode (1:2)

^[a] Sample means were based on two samples.

^[b] Wet basis

3.6. Field Layout

Treatments were randomly assigned to the plots. As shown in figure 3.1, runoff plots were paired for the convenience for applying simulated rainfall to two plots simultaneously. At three replications per treatment, including control treatment, there were 12 plots. Ammonia samplers were placed >600 cm uphill of the runoff plots to minimize cross-contamination, as shown in figure 3.1. While two ammonia samplers were installed in each replication of the control, broadcast, surface-banded, and incorporated band treatment, the reference treatment using ammonium hydroxide had only one sampler (discussed later). Runoff and ammonia volatilization studies are discussed below separately.

3.7. Runoff Study

3.7.1. Field Operations

Each runoff plot measured 1 m X 2 m and was hydrologically isolated using galvanized sheet metal borders. A steel collection trough was installed at the downstream end of each plot for runoff collection and was sealed with bentonite to prevent leakage. A collection pit was dug using a backhoe for each pair of plots. Each collection system was connected to a 68-L container using a flexible pipe. The containers were covered to prevent contamination.

The treatments were applied in a single dose to plots that had very little residue cover, except for the 9-cm tall wheat stalk. This practice followed the traditional practice of applying poultry litter in a single dose to fields prior to corn planting. In the broadcast treatments, 900 g of turkey litter were applied uniformly by hand to obtain an application rate of 4500 kg/ha. In the surface banded treatment, turkey litter bands were formed using a 10.2-cm (4-in.) wide, 1-m long piece of PVC pipe. The PVC pipe was cut in half to form a 10.2 cm (4 in.) trough and its

Figure 3.1. Layout of the field site

ends were capped. Turkey litter (300 g) was poured into the trough, shaken lightly to evenly distribute the litter, and poured over the designated areas within the plot to form a 10.2-15.2 cm (4-6 in.) band. Three turkey litter bands were applied to each banded plot for a total of 900 g of litter to obtain an application rate of 4500 kg/ha. Each band was uniformly compacted using the flat side of a spade to replicate the action of a compaction wheel. In the incorporated band treatment turkey litter was applied using the same technique as the banded application; however, the bands were incorporated using a fork to a depth of ~9 cm (3.5 in.) to replicate the action of a rotary hoe. After incorporation, the flat side of a spade was used to compact the incorporated bands.

A weather station consisting of a tipping bucket rain gauge and thermometer was installed at the field site (figure 3.1). The weather station was connected to a data logger that recorded rainfall and temperature every hour.

3.7.2. Rainfall Simulation

Rainfall simulation was conducted using a rainfall simulator described by Shelton, von Bernuth, and Rajbhandari (1985). In addition to being portable, this rainfall simulator is widely used for the USDA-ARS P runoff study being conducted nationwide. The area inside the simulator measures 3 m X 3 m and utilizes a single spray nozzle (30WSQ); the rainfall simulator uniformity coefficient is 93%. Canvas covers on the sides of the simulator eliminate wind effects. At 27.6 kPa (4 psi), the simulator applies rainfall at 7.5 cm/hr. Water is supplied to the simulator using a stationary tank and pressurized using a gasoline water pump. A pressure regulator is used to maintain desired pressure and a flow meter is used to monitor volume of water applied.

3.7.3. Runoff Collection

Covered collection tubs were left in place to collect runoff from natural rainfall events (see Figure 3.2.). The first rainfall event produced 2.2 cm on day 2, one day after turkey litter application. Since the weather station was not installed at the time when the first natural rainfall event occurred, rainfall amount was obtained from the National Weather Service's weather station at the Hart Municipal Airport ~ 2 km from the field site. Runoff samples from the first natural runoff event could not be collected because collection tub covers were blown away and samples were contaminated with rainwater. Runoff resulting from the second natural rainfall event of 0.8 cm occurring on day 3 was collected. The volume of runoff collected was recorded and a sample was obtained from each plot. The runoff samples were kept on ice until delivery to the laboratory for analysis. Samples not analyzed immediately were stored at 4°C. Due to heavy rainfall and flooding of the collection pits, on June 6, 2002, the plots were covered with plastic. The plastic cover was removed when rainfall stopped.

Figure 3.2. *Natural rainfall during the runoff study*

Rainfall simulation was applied to plots 2 and 7 d after application of treatments. Rainfall was applied at a rate of 7.5 cm/hr until runoff started as a steady stream through the collection tubes after which rainfall was applied for 30 minutes. Thereafter, rainfall was terminated and collection of runoff continued until water flow from the plot ceased. Rain gauges were installed in the plots to measure simulated rainfall. Samples of simulated runoff were collected using procedures identical to the procedure used for collecting runoff from natural rainfall.

3.7.4. Analysis of Runoff Constituents

Analysis of runoff constituents was conducted at the WVU Natural Resource Center for Coal and Energy Laboratory, Morgantown, WV. The constituents analyzed are listed in Table 3.3.

Table 3.3. *Analytical Methods Used in Testing Runoff Constituents*

Constituent	Method of Analysis
NO ₃ ⁻ -N	Colorimetric, filtered
Ammoniacal-N	Distillation and titration
TKN	Digestion, distillation and titration
Total P	Atomic emission, ICP
SBRP	Colorimetric, filtered & unfiltered
DRP	Colorimetric, filtered and unfiltered
TSS	Gravimetric

3.8. Ammonia Volatilization Study

3.8.1. Ammonia Sampler Design and Fabrication

Ammonia volatilization was measured using passive ammonia samplers (see Figure 3.3.) that utilized a filter paper impregnated with citric acid ($C_6H_8O_7$). Citric acid was used for this study because of its high efficiency in trapping NH_3 and also because it is safer to use than phosphoric acid and sulfuric acid (Rebaud, James, Ashbaugh, and Flocchini, 2001). A 0.5 M solution of citric acid was prepared by dissolving 211.34 g of citric acid granules in a mixture of 0.11 L deionized, distilled water and 2.09 L of ethanol. Glass fiber filter papers measuring 10 cm X 20 cm were soaked for 2 minutes in the citric acid solution, dried and stored separately in plastic bags. Rebaud et al. (2001) used citric acid at a concentration of 0.16 M for ammonia sampling. Compared to Rebaud et al. (2001), since greater ammonia loadings were expected in this study, a 0.5 M citric acid solution was used.

Figure 3.3. *Ammonia sampler design*

The ammonia sampler covered an area of 200 cm² (20 cm × 10 cm). Solar radiation on the aluminum roof of the sampler created natural convection causing NH₃ in the turkey litter to rise upwards, allowing it to react with the citric acid in the filter paper. The NH₃ sampler design used in this study was intended to capture ammonia volatilization occurring due to natural convection and molecular diffusion, but not forced convection (i.e., wind). The citric acid-impregnated filter paper was located 3 cm above the bare soil surface or soil surface that received turkey litter application.

Since micro-plots were used in this study, micro-meteorological methods, such as those used by Marshal et al., (1998) could not be used because of possible cross-contamination between treatments. Totally isolated samplers such as those used by Nathan and Malzer (1994) and Nommik (1973) would have created environmental conditions in the sampling area that would have greatly differed from normal environmental conditions, especially, air movement and temperature. Samplers using recirculating fans such as that used by Black, Sherlock, Cameron, Smith, and Goh (1985) were not used because of the high expense of sampling apparatus and the drastic difference in environmental conditions in the sampler compared with ambient conditions. Hence, the sampler design was considered suitable for this study.

3.8.2. Sampler Efficiency Evaluation

The ammonia trapping efficiency of the ammonia sampler was tested using reference samplers containing ammonium hydroxide (NH₄OH). Depending on the duration of sampling, 20-30 mL of NH₄OH was placed in a petri dish under the sampler at sampling time. The same volume of NH₄OH was also transferred to a HDPE bottle containing 5 mL of concentrated sulfuric acid (H₂SO₄). At the end of the sampling period, the NH₄OH remaining in the petri dish

was transferred to a HDPE bottle containing 5 mL of concentrated H₂SO₄ and taken to the laboratory for analysis. Filter paper from the reference sampler was transferred to a HDPE bottle containing 200 mL of 2 M potassium chloride (KCl) and 5 mL of concentrated H₂SO₄.

Efficiency of the ammonia sampler was calculated using the following equation.

$$\eta_{NH_3} = \frac{[NH_3]_{fp} \times 100}{[NH_3]_{in_pd} - [NH_3]_{fin_pd}} \quad [3.1]$$

where: η_{NH_3} = efficiency of NH₃ sampler, (%),

$[NH_3]_{fp}$ = NH₃ concentration in filter paper (mg),

$[NH_3]_{in_pd}$ = initial NH₃ concentration in filter paper (mg), and

$[NH_3]_{fin_pd}$ = final NH₃ concentration in filter paper (mg)

3.8.3. Field Operations

The ammonia samplers were located >600 cm (~20 feet) uphill and parallel to the runoff plots (see Figure 3.1.). Planks were installed upslope of the ammonia samplers to prevent run-on from the uphill areas. In addition to control, broadcast, banded, and incorporated band treatments, a reference treatment using ammonium hydroxide (NH₄OH) (discussed earlier) was used in the study to determine NH₃ trapping efficiency of the sampler. Treatments were assigned to the micro-plots through randomization at three replications per treatment. Except for the reference treatment, which had one sampler per replication, the other treatments had two samplers per replications to reduce variability.

Turkey litter was applied to the treatments using procedures described in the runoff study. Based on the area of the sampler (200 cm²), 9 g of turkey litter was applied in the broadcast treatment while 60 g was applied to the band or incorporated band treatments to obtain an application rate of 4500 kg/ha. A template was used to ensure that all of the applied turkey

litter stayed beneath the sampler. Ammonia volatilization was sampled 6 h, 18 h, 3 d, 5 d, 7 d, 9 d, and 11 d after treatment was applied.

Ammonia samples were collected in 250 mL HDPE bottles. Each bottle contained 200 mL of 2M KCl and 5 mL of concentrated H₂SO₄; the sample was acidified to minimize NH₃ losses during transport and storage. The bottles were transported to the laboratory on ice. Both filter papers from a replication (only one in the case of reference treatment) were transferred into a single collection bottle for analysis.

Since NH₃ volatilization increases with temperature, the heating impact of the NH₃ sampler roof was evaluated by measuring temperatures on the soil surface under the ammonia samplers and on the soil surface that was exposed to sunlight (outside the sampler). Temperatures were taken with K-type thermocouples, and recorded by a data logger at 5-minute intervals for four hours.

3.8.4. Sample Analysis

The samples were frozen prior to analysis and were analyzed using a Kjeltex 1030 autoanalyzer. Addition of excess sodium hydroxide to an aliquot of the sample resulted in release of ammonia in gaseous form, which was then distilled in a saturated solution of boric acid. The boric acid-ammonia complex was titrated with a known volume of 0.1 M HCl to determine ammonia concentration in the sample solution. Based on the total volume of solution and ammonia concentration in the solution, ammonia-N volatilization (g/ha) was determined.

Chapter 4

Results and Discussion

Objective I was achieved by conducting a runoff study utilizing different turkey litter application methods. In addition to runoff volume, runoff water quality was also considered. Objective II was achieved with the use of ammonia samplers.

4.1 Water Quality Study

Objective I: Evaluate the effects of different turkey litter application methods on total runoff volume as well as nitrate-N (NO_3^- -N), ammoniacal-N (NH_4^+ -N + NH_3 -N), total Kjeldahl N (TKN), total P (TP), dissolved reactive P (DRP), sediment bound reactive P (SBRP), and total suspended solids (TSS) concentrations in surface runoff.

4.1.1. Runoff Volume

Treatment impact on runoff volume is presented in Table 4.1. Analysis of Variance (ANOVA) indicated that there was no significant difference in runoff volume ($\alpha = 0.05$) among treatments in any of the runoff events. The statistical outputs are presented in Appendix B.

Given that all plots were partially bare due to removal of baled hay, lower runoff (due to greater infiltration) had been expected in incorporated band treatment than the other treatments for the first event (natural runoff). However, high within-treatment variability (as indicated by high standard deviation values) (see Table 4.1.) could have resulted in lack of significant difference among treatments in all events. For the remaining runoff events, surface sealing due to raindrop impact likely neutralized the impact of tillage in the incorporated band treatment versus the other treatments.

Table 4.1. *Treatment Effect on Runoff Volume: Results of the Statistical Analysis at $\alpha = 0.05$ ^[a]*

Treatment	Runoff Volume (m ³ /ha)					
	Natural Runoff		Simulated Runoff Event 1		Simulated Runoff Event 2	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Broadcast	9.5	6.0	130.9	37.0	52.6	39.8
Band	8.8	6.4	103.4	32.8	65.2	47.2
Incorporated band	3.5	1.4	86.1	59.5	71.0	45.7
Control	14.8	12.6	161.5	18.5	117.1	64.0
F-value	1.10		1.44		0.95	
p-value	0.40		0.30		0.43	

^[a] Mean of three replications.

4.1.2. Nitrate-Nitrogen

Treatment impact on NO₃⁻-N loading is presented in Table 4.2. While ANOVA was used to evaluate the natural runoff and simulated event 2, simulated event 1 was evaluated using the general linear model (GLM) due to the presence of unbalanced data sets. Nitrate nitrogen concentrations are presented in Appendix A. The statistical outputs are presented in Appendix B.

At $\alpha = 0.05$, there were no significant difference among treatments in any of the events (see Table 4.2). Since turkey litter is low in NO₃⁻-N concentrations (Collins, Barker, Carr, Brodie, and Martin, 1999) little or no difference in NO₃⁻-N loadings among the treatments had been expected. Again, high within treatment variability (as indicated by high standard deviation values) could have resulted in lack of significant difference among treatments.

Table 4.2. *Treatment Effect on NO_3^- -N: Results of the Statistical Analysis at $\alpha = 0.05$ ^[a]*

Treatment	NO ₃ ⁻ -N (g/ha)						Total Losses
	Natural Runoff		Simulated Rainfall Event 1		Simulated Rainfall Event 2		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Broadcast	0.2	0.2	12.9	4.3	17.2	18.0	30.3
Band	0.3	0.1	1.3 ^[b]	1.0	31.1	27.8	32.7
Incorporated band	0.5	0.3	20.0	16.5	25.8	26.2	46.3
Control	0.7	0.3	13.7	2.4	24.8	13.7	39.2
F-value	2.43		1.65		0.20		
p-Value	0.14		0.26		0.89		

^[a] Mean of three replications, except where indicated.

^[b] Mean of two replications.

Lower NO_3^- loading during the natural rainfall could have been due to the smaller depth of rainfall (0.8 cm) compared with 6.4 cm at 7.5 cm/h in averaged over all treatments, in simulated rainfall event 1. Based on the mean data, compared with simulated runoff event one, higher NO_3^- -N losses in simulated runoff event two could be attributed to greater availability of NO_3^- -N for loss in runoff due to conversion of organic-N and NH_4^+ -N into NO_3^- -N during the intervening period (7 days). Overall, NO_3^- -N loadings were low for all treatments.

4.1.3. Ammoniacal-Nitrogen

Treatment impact on NH_4^+ -N losses was tested in each of the runoff events. Natural runoff and simulated runoff event two were calculated using ANOVA. Because of unbalanced data sets in simulated runoff event one, GLM was used. Means, standard deviations, and

p-values are presented in Table 4.3. Ammoniacal-N concentrations are presented in Appendix A. The statistical outputs are presented in Appendix B.

Table 4.3. *Treatment Effect on Ammoniacal - N: Results of the Statistical Analysis at $\alpha = 0.05$ ^[a]*

Treatment	Ammoniacal N (g/ha)						Total Losses
	Natural Rainfall		Simulated Rainfall Event 1		Simulated Rainfall Event 2		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Broadcast	23.1	17.1	148.3	75.4	5.2	2.8	176.6
Band	20.2	17.1	249.1 ^[b]	187.2	9.6	10.3	278.9
Incorporated band	0.6	0.5	52.2	55.1	5.1	5.4	57.9
Control	1.9	2.2	10.8	8.00	5.1	3.3	17.8
F-value	2.87		3.64		0.39		
p-Value	0.10		0.26		0.76		

^[a] Mean of three replications, except where indicated.

^[b] Mean of two replications.

At $\alpha = 0.05$, there was no significant difference among treatments in any of the events (see Table 4.3). High within treatment variability (as indicated by high standard deviation values) could have resulted in lack of significant difference among treatments.

Incorporated band application had been expected to result in significantly lower levels of ammoniacal-N loading (due to reduced availability on the soil surface) than the other turkey litter application treatments. Compared with band application, incorporation of turkey litter could be expected to result in greater soil to litter contact, thus allowing soil microbes to convert ammoniacal N to NO_3^- -N more rapidly. Based on the means data, compared to simulated runoff event one, lower ammoniacal-N losses in the second simulated event could be attributed to

nitrification, movement of NH_4^+ -N into the soil, as well as ammoniacal-N depletion by runoff from the earlier rainfall events.

4.1.4. Total Kjeldahl Nitrogen

Treatment impact on TKN loading is presented in table 4.2. While ANOVA was used to evaluate the natural runoff and simulated event 2, simulated event 1 was evaluated using the general linear model (GLM) due to the presence of unbalanced data sets. Total Kjeldahl N concentrations are presented in Appendix A. Statistical outputs are presented in Appendix B.

Table 4.4. *Treatment Effect on TKN: Results of the Statistical Analysis at $\alpha = 0.05$ ^[a]*

Treatment	TKN (g/ha)						Total Losses
	Natural Runoff		Simulated Runoff Event 1		Simulated Runoff Event 2		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Broadcast	1039.2	1103.7	1215.8	391.0	494.3	472.5	2749.3
Band	698.8	478.7	1502.1 ^[b]	1045.0	478.1	242.1	2679.0
Incorporated band	247.1	125.4	1522.2	1206.6	773.7	642.6	2543.2
Control	1011.0	797.5	1491.4	35.1	591.5	48.3	3093.9
F-value	0.78		0.10		0.32		
p-value	0.54		0.96		0.81		

^[a] Mean of three replications, except where indicated.

^[b] Mean of two replications.

At $\alpha = 0.05$, there was no significant difference among treatments in any of the events (see Table 4.3.). It had been expected that incorporated band treatments would have resulted in lower TKN losses than the other turkey litter treatments due to reduced availability on the

surface for transport in runoff. Again, high within treatment variability (as indicated by high standard deviation values) could have resulted in lack of significant difference among treatments.

Based on the means data, TKN loadings in runoff were generally greater in simulated runoff event one than in the second simulated event probably due to depletion of TKN in the earlier runoff events as well as conversion of organic N to NO_3^- -N through mineralization.

Based on TKN (see Table 4.4) and ammoniacal – N (see Table 4.2) loadings, organic N loadings were higher than inorganic N loadings in all treatments and events.

4.1.5. Dissolved Reactive Phosphorus

Treatment effect on DRP is presented in Table 4.4. Natural runoff and simulated runoff event two were analyzed using ANOVA. Because of unbalanced data sets in simulated runoff event one, GLM was used for calculations. Dissolved reactive P concentrations data is presented in Appendix A. Statistical outputs are presented in Appendix B.

Table 4.5. *Treatment Effect on DRP: Results of the Statistical Analysis at $\alpha = 0.05$ ^[a]*

Treatment	DRP (g/ha)						Total Losses
	Natural Runoff		Simulated Runoff Event 1		Simulated Runoff Event 2		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Broadcast	4.0	4.3	258.3	158.9	20.7	15.3	283.0
Band	7.2	5.6	442.8 ^[b]	330.3	47.8	36.8	497.8
Incorporated band	1.2	0.7	53.7	46.5	21.3	15.9	76.2
Control	4.0	3.0	50.6	13.1	25.3	16.1	156.1
F-value	1.21		3.61		0.94		
p-value	0.37		0.26		0.46		

^[a] Mean of three replications, except where indicated.

^[b] Mean of two replications.

At $\alpha = 0.05$, there was no significant difference among treatments in any of the events (see Table 4.5). Compared with other treatments, DRP losses were expected to be lower in incorporated bands because little of the P in litter would be available on the soil surface for transport in runoff. Again, high within treatment variability (as indicated by high standard deviation values) could have resulted in lack of significant difference among treatments.

Based on mean values, DRP losses were much higher in simulated runoff event one than the other events. The natural rainfall event (0.8 cm) produced low volume of runoff that resulted in lower DRP loadings, compared with the simulated runoff events. Since DRP is not only removed in runoff, but also in percolating water (resulting in conversion of some DRP to SBRP), simulated runoff event two resulted in lower DRP loading than in the earlier events due to DRP removal by the previous runoff events.

4.1.6. Sediment Bound Reactive Phosphorus

Treatment impact on SBRP loading is presented in Table 4.6. While ANOVA was used to evaluate the natural runoff and simulated event 2, simulated event 1 was evaluated using GLM, due to the presence of unbalanced data sets. Sediment bound reactive P concentrations are presented in Appendix A. Statistical outputs are presented in Appendix B.

At $\alpha = 0.05$, there was no significant difference among treatments in any of the events (see Table 4.6). Again, high within treatment variability (as indicated by high standard deviation values) could have resulted in lack of significant difference among treatments. Higher losses were experienced in simulated runoff event one compared with the other events. Natural rainfall produced lower runoff volume and hence, lower SBRP loadings compared with the simulated events. Natural runoff event and the first simulated runoff event likely removed most of the

SBRP in the runoff, thus resulting in lower loadings in simulated event two. Dissolved reactive P loadings were higher than SBRP probably due to wet, and hence, anaerobic conditions on the plots that likely increased conversion of SBRP to DRP. Because DRP is in solution it is easier to transport than SBRP and could result in higher DRP loading.

Table 4.6. *Treatment Effect on SBRP: Results of the Statistical Analysis at $\alpha = 0.05$ ^[a]*

Treatment	SBRP (g/ha)						Total Losses
	Natural Runoff		Simulated Runoff Event 1		Simulated Runoff Event 2		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Broadcast	10.6	8.2	1.5	2.6	0.9	1.0	13.0
Band	4.7	3.8	130.3 ^[b]	151.8	2.3	2.5	137.3
Incorporated band	0.5	0.3	20.3	32.4	1.0	0.9	21.8
Control	0.9	0.6	2.6	0.7	2.1	1.6	5.6
F-value	0.08		2.33		0.61		
p-value	0.84		0.16		0.63		

^[a] Mean of three replications, except where indicated.

^[b] Mean of two replications.

4.1.7. Total Phosphorus

Treatment impact TP loading is presented in Table 4.7. While ANOVA was used to evaluate the natural runoff and simulated event 2, simulated event 1 was evaluated using GLM due to the presence of unbalanced data sets. Total P concentration data are presented in Appendix A. Statistical outputs are presented in Appendix B.

At $\alpha = 0.05$, there was no significant difference among treatments in any of the events (see Table 4.7). It had been expected that total P loading in runoff would be lower in

incorporated bands than other turkey litter treatments due to incorporation which would reduce P available for removal in runoff. Again, high within treatment variability (as indicated by high standard deviation values) could have resulted in lack of significant difference.

Table 4.7. *Treatment Effect on TP: Results of the Statistical Analysis at $\alpha = 0.05$* ^[a]

Treatment	TP (g/ha)						Total Losses
	Natural Runoff		Simulated Runoff Event 1		Simulated Runoff Event 2		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Broadcast	56.1	46.5	246.3	46.8	22.9	12.0	325.3
Band	36.7	27.7	717.0 ^[b]	732.1	47.5	24.3	801.2
Incorporated band	7.2	5.0	269.8	233.4	107.6	82.3	384.6
Control	16.8	7.7	213.6	141.0	140.9	104.4	371.3
F-value	1.88		1.26		1.91		
p-value	0.21		0.07		0.21		

^[a] Mean of three replications, except where indicated.

^[b] Mean of two replications.

Based on mean values, higher total P losses in all treatments in the first simulated event than the natural event was likely due to greater depth and intensity of rainfall resulting in more runoff and hence, greater removal of P. Again, based on mean loadings, lower total P concentrations in the second simulated event could have been due to mineralization of P into DRP and its movement into the soil as well as depletion of total P by runoff from the first simulated event. Based on mean values, inorganic P losses were generally higher than organic P losses based on SBRP (see Table 4.6.) loadings and DRP (see Table 4.5.) loadings.

4.1.8 Total Suspended Solids

Treatment impact on TSS loading is presented in Table 4.8. While ANOVA was used to evaluate the natural runoff and simulated event 2, simulated event 1 was evaluated using GLM due to the presence of unbalanced data sets. Total suspended solids concentrations are presented in Appendix A. Statistical outputs are presented in Appendix B.

Table 4.8. *Treatment Effect on TSS: Results of the Statistical Analysis at $\alpha = 0.05$ ^[a]*

Treatment	TSS (kg/ha)						Total Losses
	Natural Runoff		Simulated Runoff Event 1		Simulated Runoff Event 2		
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	
Broadcast	1.4	0.6	13.5	6.1	1.2	0.7	16.1
Band	1.6	0.7	10.2 ^[b]	2.4	0.3	0.5	12.1
Incorporated band	0.3	0.1	7.2	4.7	0.0	0.0	7.5
Control	1.3	1.4	17.7	2.4	2.2	3.8	21.2
F-value	1.57		3.09		0.77		
p-value	0.27		0.10		0.54		

^[a] Mean of three replications, except where indicated.

^[b] Mean of two replications.

At $\alpha = 0.05$, there were no significant difference among treatments in any of the events (table 4.8). High within treatment variability (as indicated by high standard deviation values) may have contributed to the lack of significant differences among treatments.

The natural rainfall produced low runoff volumes (see Table 4.1), thus contributing to low TSS loadings. Based on mean values, simulated runoff event one produced the highest SS loadings since runoff volumes were the highest in that event (see Table 4.1).

4.2. Ammonia Volatilization Study

Objective II: Evaluate NH_3 volatilization losses from the three turkey litter application methods.

The ammonia volatilization study was conducted for 11 d, after application of treatments. The study involved seven sampling events, namely, 0-6 h (event 1), 6-24 h (event 2), 24-72 h (event 3), 72-120 h (event 4), 120-168 h (event 5), 168-216 h (event 6), and 216-264 h (event 7).

4.2.1. Event One (0- 6 h, 6 h duration)

Treatment impact on NH_3 volatilization during event 1 is given in Figure 4.1. The treatments were significantly different (ANOVA $p = <0.01$; $\alpha = 0.05$). Statistical outputs are presented in Appendix B.

With pairwise comparison, band application produced significantly higher $\text{NH}_3\text{-N}$ volatilization losses ($\text{LSD} = 40.5 \text{ g/ha}$) than the other treatments (see Figure 4.1). It had been expected that broadcast application would have resulted in the highest NH_3 volatilization. Since broadcast application allowed for greater soil contact (due to thin residue cover), the lower soil pH (6.7) could have reduced the pH of turkey litter (8.5) resulting in little of the ammoniacal-N being in the $\text{NH}_3\text{-N}$ form. Also, greater soil-litter contact allowed for conversion of NH_3 into the more stable NH_4^+ form in the broadcast treatment compared to band application. However, high variability in the broadcast treatment likely masked treatment effects compared with incorporated band treatment.

Figure 4.1. Ammonia volatilization during event one (0-6 h, 6-h duration), event two (6-24 h, 18-h duration), and event three (24-72 h, 48-h duration). Mean values are based on three replications. Maximum and minimum values are indicated. Treatment impacts on NH₃ volatilization were significant ($\alpha = 0.05$) for events one and two. Hence, for events one and two, treatment means in the same sampling event, followed by the same letter are not significantly different at $\alpha = 0.05$ using Fisher's least significant difference (LSD)

4.2.2. Event Two (6-24 h, 18 h duration)

Treatment impact on NH_3 volatilization during event 2 is given in Figure 4.1. The treatments were significantly different (ANOVA $p = <0.01$; $\alpha = 0.05$). Statistical outputs are presented in Appendix B.

Band application resulted in significantly higher NH_3 volatilization losses (LSD = 27.7 g/ha) than the other treatments. While the broadcast and control treatments were significantly different, the incorporated band treatment was not significantly different than the broadcast and control treatments. While reasons for higher NH_3 losses from the band treatment are discussed earlier, high variability in the broadcast and incorporated band treatments likely masked treatment differences.

During this sampling event, raindrop splashing caused soil and possibly, turkey litter particles to be splashed onto the glass fiber filter, possibly, causing some contamination. However, soil and litter were likely to have caused very little ammoniacal-N to be deposited on the glass fiber filter.

4.2.3. Event Three (24-72 h, 48 h duration)

Treatment impact on NH_3 volatilization during event 3 is given in Figure 4.1. The treatments were not significantly different (ANOVA $p = 0.13$; $\alpha = 0.05$). Statistical outputs are presented in Appendix B.

Runoff due to natural rainfall (5.3 cm) during this sampling event likely transported NH_3 into the soil as well as in runoff, and hence, reduced NH_3 available for volatilization. Splashing due to raindrop impact possibly caused some contamination of the filter paper with ammoniacal - N from the soil and possibly, turkey litter. Treatment effects on NH_3 volatilization could have

been masked by high within-treatment variability. The reasons for comparable NH_3 volatilization from the control treatment that received no turkey litter and the turkey litter treatments were unclear, however mineralization of wheat stalk on the soil surface may have produced some NH_3 .

4.2.4. Event Four (72 – 120 h, 48 h duration)

Treatment impact on NH_3 volatilization during event 4 is given in Figure 4.2. The treatments were not significantly different (ANOVA $p = 0.06$; $\alpha = 0.05$). Statistical outputs are presented in Appendix B. Lack of significant difference may be due to high within treatment variability.

4.2.5. Event Five (120–168 h, 48 h duration)

Treatment impact on NH_3 volatilization during event 5 is given in Figure 4.2. The treatments were significantly different (ANOVA $p = 0.02$; $\alpha = 0.05$). Statistical outputs are presented in Appendix B.

Pairwise comparison indicated that broadcast and control treatments produced significantly higher NH_3 volatilization losses ($\text{LSD} = 25.5 \text{ g/ha}$) than did band and incorporated band treatments. High NH_3 volatilization losses so late in the study in the broadcast treatment were unexpected. Also unexpected was the high NH_3 volatilization losses in the control treatment, though, mineralization of organic matter resulting in the release of NH_3 could not be ruled out. Compared with the broadcast treatment, depletion of NH_3 through both, volatilization (during the previous sampling event) and mineralization likely resulted in reduced NH_3 losses in the band treatment. In the incorporated band treatment, conservation of ammoniacal-N as NH_4^+

Figure 4.2. Ammonia volatilization during event four (72-120 h, 48-h duration), event five (120-168 h, 48-h duration), and event six (168-216h, 48-h duration). Mean values are based on three replications. Maximum and minimum values are indicated. Treatment impacts on NH₃ volatilization were significant ($\alpha = 0.05$) for events five and six. Hence, for events five and six, treatment means in the same sampling event, followed by the same letter are not significantly different at $\alpha = 0.05$ using Fisher's least significant difference (LSD).

as well as nitrification (as evidenced by high NO_3^- -N loadings in the first simulated runoff event) likely contributed to low NH_3 volatilization losses.

4.2.6. Event Six (168 – 216 h, 48 h duration)

Treatment impact on NH_3 volatilization during event 4 is given in figure 4.2. The treatments were significantly different (ANOVA $p = <0.01$; $\alpha = 0.05$). Statistical outputs are presented in Appendix B.

Pairwise comparisons indicated that the broadcast and control treatments produced significantly higher NH_3 volatilization losses (LSD = 27.8 g/ha) than did band and incorporated band treatments. It was unclear why the control treatment gave significantly higher NH_3 loadings than band and incorporated band treatments, though mineralization of organic matter resulting in release of NH_3 seemed a partial explanation.

4.2.7. Event Seven (216 – 264 h, 48 h duration)

Treatment impact on NH_3 volatilization during event 7 is given in Figure 4.1. The treatments were significantly different (ANOVA $p = <0.01$; $\alpha = 0.05$). Statistical outputs are presented in Appendix B.

As Figure 4.3 indicates, all treatments in event seven were significantly different (LSD = 10.7 g/ha) from each other. The control treatment produced the second highest NH_3 losses, which was unexpected. However, compared with other treatments, the lowest NH_3 loss in incorporated band treatment was expected.

Figure 4.3. Ammonia volatilization during event seven (216-264 h, 48-h duration) and total NH₃ volatilization losses. Maximum and minimum values are indicated for event seven. Treatment impacts on NH₃ volatilization were significant ($\alpha = 0.05$) for event seven, hence, treatment means followed by the same letter are not significantly different at $\alpha = 0.05$ using Fisher's least significant difference (LSD). Statistical analysis was not conducted to compare treatment impacts for total NH₃ volatilization losses for the entire study duration.

4.2.8. Total Ammonia Volatilization Losses and Trends

Total NH_3 volatilization losses are presented in Figure 4.3. While the reasons for high NH_3 volatilization losses in the band and broadcast applications could be explained, reasons for comparatively high NH_3 volatilization losses in the control treatment (>3 times greater than the incorporated band treatment) were unclear. Incorporation of both turkey litter and residue into the soil in the incorporated band treatment likely resulted in conservation of NH_3 due to conversion to NH_4^+ and then to NO_3^- resulting in reduced NH_3 volatilization.

Ammonia loss trend for the study duration is presented in Figure 4.4. Typical ammonia loss curves exhibit large losses soon after application and quickly decrease to low, steady levels. Banded and incorporated band treatments exhibited somewhat typical ammonia loss trends. Broadcast and control treatments exhibited unexpected ammonia loss trends. However, ammonia loss trends from broadcast and control treatments were similar.

Trapping efficiency of the ammonia sampler, calculated using Equation [3.1.], is presented in Table 4.9. When trapping efficiency is taken into consideration, the NH_3 volatilization losses become more than 10 times greater than measured losses.

Figure 4.4. Ammonia loss trend for duration of NH₃ volatilization study

Table 4.9. *Efficiency of NH₃ Samplers* ^[a]

Sampling event	Duration of sampling after turkey litter application (h)	NH ₃ trapping efficiency
1	0-6 h	23.5% ^[b]
2	18-24 h	10.7%
3	24-72 h	1.7%
4	72-120 h	3.3%
5 ^[c]	120-168h	14.1%
6	168-216 h	18.0%
7 ^[c]	216-264 h	1.2%
Full period ^[d]		8.2%

^[a] Mean efficiency based on three replications, except where noted.

^[b] Based on NH₃-N in 20 mL of NH₄OH.

^[c] Means based on two samples.

^[d] Total mean was weighted based on a 11d sampling event.

Since a positive correlation exists between NH₃ volatilization and temperature, lower temperatures in the ammonia samplers (during sunlight hours) could have reduced volatilization losses (see Figure 4.5.). It was observed that with cloud cover, temperature difference outside and inside the samplers were reduced, hence it was likely that temperature differences were lower during night than during daylight hours.

Figure 4.5. *Soil surface temperature under ammonia sampler and exposed to sunlight*

4.3 Environmental Impacts of Turkey Litter Application

In the water quality study, no significant differences between the treatments were observed. However, based on mean values and total losses, some differences in nutrient losses were observed among treatments. Incorporated band treatment resulted in lower ammoniacal -N and DRP loadings than other treatments. Also, broadcast and band treatments produced approximately two times higher TSS as the incorporated band treatment. Broadcast application and incorporated band application exhibited lower SBRP and TP than did the band treatment.

In the NH_3 volatilization study, banded application consistently produced greater NH_3 losses than other treatments early in the study; beginning event 5, broadcast application resulted in higher NH_3 volatilization losses. Incorporated band application produced the lowest total NH_3 losses. Broadcast and band application had five times more NH_3 volatilization losses than the incorporated band application.

Chapter 5

Summary and Conclusions

The environmental impacts of three turkey litter application methods, namely, broadcasting, banding, and incorporated banding of turkey litter were compared with respect to runoff water quality and ammonia volatilization. A control treatment was included to evaluate the impact of background nutrients on water quality and ammonia volatilization.

Turkey litter was applied to plots at 4500 kg/ha basis. Runoff water quality was evaluated for a natural rainfall event as well as two simulated rainfall events. Runoff water volume was measured and examined for the following constituents: NO_3^- -N, ammoniacal - N, TKN, TP, SBRP, DRP, and TSS. All treatments were applied in triplicate.

The water quality study provided the following results.

1. At $\alpha = 0.05$, the treatments were not significantly different with respect to loadings of any of the constituents.
2. Totaled over the three runoff events, incorporated banding produced substantially lower total loadings of ammoniacal – N, DRP and TSS than the broadcast and band treatments.

Ammonia volatilization losses were compared among treatments using passive samplers for seven sampling events over 11 d. Ammonia trapping efficiency was evaluated using a reference sampler.

The NH_3 volatilization study provided the following results.

1. In five (events 1, 2, 5, 6, 7) of seven sampling events where treatment impact was statistically significant, the banding treatment had the highest NH_3 volatilization losses in the first two events. The broadcast and control treatments resulted in the highest NH_3 volatilization losses in events 5 and 6 while the broadcast treatment had the highest NH_3 volatilization losses in the last event.
2. As expected, NH_3 volatilization loss in the incorporated band treatment was lower in three of five sampling events when a treatment impact on NH_3 volatilization was significant.
3. Overall, totaled over the entire study period, NH_3 losses were five times lower for the incorporated band treatment than the other turkey litter application methods.
4. The NH_3 trapping efficiency of the sampler was low, at 8.2%.

The overall conclusion of this study was that the incorporated band treatment offered the potential to reduce ammoniacal -N and DRP losses in runoff and NH_3 volatilization losses. Further research should be conducted to better evaluate incorporated band vs. broadcast treatments in a cropped situation for both crop yield and water quality.

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Appendix A
Constituent Concentrations
in Runoff

Table A1 *Runoff Constituent Concentrations for Natural Runoff*

Plot	Treatment	Runoff vol.,	Concentration, mg/L						
		L	Nitrate-N	Ammonia-N	TKN	Total-P	DRP	SBRP	TSS
1	Broadcast	1.27	bdl	2.12	109.50	5.66	0.27	0.79	274
2	Broadcast	3.26	0.02	2.63	139.50	6.70	0.55	1.23	102
3	Band	0.7	0.10	0.68	51.39	2.56	0.77	0.11	320
4	Band+inc	0.5	0.12	0.21	78.43	1.11	0.32	0.20	62
5	Band+inc	1	0.16	0.23	77.99	2.52	0.40	0.14	68
6	Control	2.21	0.09	0.05	75.20	1.91	0.38	0.14	70
7	Broadcast	1.15	0.02	2.26	25.80	4.01	0.22	1.17	116
8	Control	0.9	0.12	0.14	70.89	1.74	0.20	0.11	72
9	Band+inc	0.6	0.09	0.04	51.78	2.08	0.30	0.06	90
10	Band	1.45	0.03	2.99	109.40	5.06	0.76	0.81	172
11	Control	5.75	0.01	0.15	65.50	0.74	0.24	0.02	100
12	Band	3.1	0.03	2.35	72.47	4.15	0.87	0.50	150

Table A2 *Runoff Constituent Concentrations for Simulated Runoff Event 1*

Plot	Treatment	Runoff vol.,	Concentration, mg/L						
		L	Nitrate-N	Ammonia-N	TKN	Total-P	DRP	SBRP	TSS
1	Broadcast	23.75	0.07	1.21	10.04	1.62	1.76	0	94
2	Broadcast	40	0.08	1.13	8.09	1.35	2.18	0	102
3	Band	13.9	0.03	1.68	10.98	2.86	3.01	0.33	122
4	Band+inc	5.2	0.10	0.21	20.37	0.14	0.10	0.01	70
5	Band+inc	29	0.15	0.26	19.76	3.03	0.45	0.02	74
6	Control	36	0.06	0.02	8.51	0.28	0.27	0.01	110
7	Broadcast	14.75	0.19	1.02	11.35	3.75	1.76	0.06	120
8	Control	28.6	0.10	0.07	10.31	2.00	0.27	0.02	106
9	Band+inc	17.45	0.41	1.29	13.43	4.20	1.07	0.66	102
10	Band	27	0.00	2.83	16.60	9.15	5.01	1.76	88
11	Control	32.3	0.10	0.12	9.09	1.88	0.40	0.02	112
12	Band	21.1	NA	NA	NA	NA	NA	NA	NA

Table A3 *Runoff Constituent Concentrations for Simulated Runoff Event Two*

Plot	Treatment	Runoff vol.,	Concentration, mg/L						
		L	Nitrate-N	Ammonia-N	TKN	Total-P	DRP	SBRP	TSS
1	Broadcast	6.8	0.17	0.09	7.712	0.274	0.33	0.00	20
2	Broadcast	5.1	0.31	0.16	7.169	1.07	0.49	0.03	78
3	Band	2.9	0.13	0.05	16.068	1.36	0.38	0.05	58
4	Band+inc	3.65	0.08	0.05	6.852	0.72	0.25	0.01	0
5	Band+inc	19.45	0.23	0.03	14.5	1.5	0.24	0.02	0
6	Control	17.4	0.20	0.03	6.661	0.702	0.19	0.02	76
7	Broadcast	19.65	0.39	0.08	10.565	0.326	0.39	0.02	8
8	Control	14.75	0.22	0.05	7.462	1.39	0.21	0.01	0
9	Band+inc	19.5	0.55	0.12	8.061	1.68	0.37	0.01	0
10	Band	21.55	0.53	0.19	6.655	0.536	0.60	0.01	0
11	Control	38.1	0.21	0.05	3.384	1.36	0.23	0.02	0
12	Band	14.65	0.47	0.10	6.609	0.886	1.00	0.07	0

Appendix B

Statistical Outputs

Table B1 *Statistical Output of Runoff Volume for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.647158333	3	2.549052778	1.099089	0.404101
Within Groups	18.55393333	8	2.319241667		
Total	26.20109167	11			

Table B2 *Statistical Output of $\text{NO}_3^- - \text{N}$ for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.419388245	3	0.139796082	2.433019	0.139971
Within Groups	0.459662982	8	0.057457873		
Total	0.879051227	11			

Table B3 *Statistical Output of Ammoniacal - N for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1264.640855	3	421.5469518	2.864753	0.103988
Within Groups	1177.196	8	147.1495		
Total	2441.836856	11			

Table B4 *Statistical Output of TKN for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1221799.496	3	407266.4986	0.776132	0.539388
Within Groups	4197910.391	8	524738.7989		
Total	5419709.887	11			

Table B5 *Statistical Output of TP for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4249.319773	3	1416.439924	1.882175	0.210996
Within Groups	6020.439744	8	752.554968		
Total	10269.75952	11			

Table B6 *Statistical Output of DRP for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	54.11487523	3	18.03829174	1.21317	0.365828
Within Groups	118.9498508	8	14.86873135		
Total	173.0647261	11			

Table B7 *Statistical Output of SBRP for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	198.6034142	3	66.20113808	3.198654	0.083739
Within Groups	165.572505	8	20.69656313		
Total	364.1759192	11			

Table B8 *Statistical Output of TSS for the Natural Runoff Event*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3128641.75	3	1042880.583	1.568551	0.271124
Within Groups	5318950.187	8	664868.7733		
Total	8447591.937	11			

Table B9 *Statistical Output of Runoff Volume for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Between Groups	3	392.036	130.679	1.443	0.301
Within Groups	8	724.310	90.539	1.443	
Total	11	1116.346			

Table B10 *Statistical Output of $\text{NO}_3^- - \text{N}$ for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Model	3	419.510067	139.836689	1.65	0.2629
Error	7	592.815733	84.687962		
Corrected Total	10	1012.325800			

Table B11 *Statistical Output of Ammoniacal - N for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Model	3	82069.6186	27356.5395	3.64	0.0724
Error	7	52634.1322	7519.1617		
Corrected Total	10	134703.7508			

Table B12 *Statistical Output of TKN for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Model	3	184744.165	61581.388	0.10	0.9575
Error	7	4311977.329	615996.761		
Corrected Total	10	4496721.494			

Table B13 *Statistical Output of TP for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Model	3	372099.645	124033.215	1.26	0.3598
Error	7	690258.040	98608.291		
Corrected Total	10	1062357.685			

Table B14 *Statistical Output of DRP for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Model	3	254532.1986	84844.0662	3.61	0.0733
Error	7	164295.8720	23470.8389		
Corrected Total	10	418828.0706			

Table B15 *Statistical Output of SBRP for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Model	3	25080.24090	8360.08030	2.33	0.1612
Error	7	25148.54107	3592.64872		
Corrected Total	10	50228.78196			

Table B16 *Statistical Output of TSS for Simulated Runoff Event 1*

	Df	Sum of Squares	Mean Square	F	Sig.
Model	3	179575915.7	59858638.6	3.09	0.0993
Error	7	135784640.8	19397805.8		
Corrected Total	10	315360556.5			

Table B17 *Statistical Output of Runoff Volume for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	285.3241667	3	95.10805556	0.953142	0.459915
Within Groups	798.27	8	99.78375		
Total	1083.594167	11			

Table B18 *Statistical Output of NO_3^- - N for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	295.6232626	3	98.54108754	0.199491	0.893856
Within Groups	3951.70604	8	493.963255		
Total	4247.329303	11			

Table B19 *Statistical Output of Ammoniacal - N for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	45.0967955	3	15.03226517	0.390706	0.763081
Within Groups	307.7970521	8	38.47463151		
Total	352.8938476	11			

Table B20 *Statistical Output of TKN for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	165919.8068	3	55306.60228	0.31732	0.81277
Within Groups	1394341.028	8	174292.6285		
Total	1560260.834	11			

Table B21 *Statistical Output of TP for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	26373.57518	3	8791.191728	1.909825	0.206509
Within Groups	36825.11923	8	4603.139904		
Total	63198.69442	11			

Table B22 *Statistical Output of DRP for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1486.10851	3	495.3695033	0.942161	0.464453
Within Groups	4206.242171	8	525.7802714		
Total	5692.350681	11			

Table B23 *Statistical Output of SBRP for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.636779167	3	1.545593056	0.606108	0.629373
Within Groups	20.40024583	8	2.550030729		
Total	25.037025	11			

Table B24 *Statistical Output of TSS for Simulated Rainfall Event 2*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8872244.667	3	2957414.889	0.771302	0.541754
Within Groups	30674525.33	8	3834315.667		
Total	39546770	11			

Table B25 *Statistical Output of Ammonia Volatilization for Event 1*

	df	Sum of Squares	Mean Square	F	Sig.
Model	3	29647.82000	9882.60667	13.86	0.0016
Error	8	5706.04667	713.25583		
Corrected Total	11	35353.86667			

Table B26 *Statistical Output of Ammonia Volatilization for Event 2*

	df	Sum of Squares	Mean Square	F	Sig.
Model	3	8617.88667	2872.62889	8.67	0.0068
Error	8	2652.15333	331.51917		
Corrected Total	11	11270.04000			

Table B27 *Statistical Output of Ammonia Volatilization for Event 3*

	df	Sum of Squares	Mean Square	F	Sig.
Model	3	3153.606667	1051.202222	2.51	0.1325
Error	8	3349.493333	418.686667		
Corrected Total	11	6503.100000			

Table B28 *Statistical Output of Ammonia Volatilization for Event 4*

	df	Sum of Squares	Mean Square	F	Sig.
Model	3	5961.98917	1987.32972	3.65	0.0635
Error	8	4355.00000	544.37500		
Corrected Total	11	10316.98917			

Table B29 *Statistical Output of Ammonia Volatilization for Event 5*

	df	Sum of Squares	Mean Square	F	Sig.
Model	3	5024.570000	1674.856667	5.94	0.0197
Error	8	2257.020000	282.127500		
Corrected Total	11	7281.590000			

Table B30 *Statistical Output of Ammonia Volatilization for Event 6*

	df	Sum of Squares	Mean Square	F	Sig.
Model	3	9606.56250	3202.18750	9.54	0.0051
Error	8	2686.36667	335.79583		
Corrected Total	11	12292.92917			

Table B31 *Statistical Output of Ammonia Volatilization for Event 7*

	df	Sum of Squares	Mean Square	F	Sig.
Model	3	6867.763333	2289.254444	46.37	<0.0001
Error	8	394.926667	49.365833		
Corrected Total	11	7262.690000			

Appendix C

Definition of Terms

Ammonia Volatilization- A mechanism of N loss to the atmosphere that occurs naturally in all soils.

Incorporated band- Application method in which litter is dribbled onto the soil surface in bands 10-15 cm wide, at 75 cm row spacing. Incorporation occurs immediately after application only in the banded area resulting in the mixture of soil with litter.

Leaching- The movement of dissolved solute with percolating water deeper into the soil profile.

Non-point source pollution- Air and water pollution sources that cannot be specifically identified as coming from discrete, unidentifiable points.

Runoff- Water movement along the soil surface occurring from precipitation and run on.

Poultry litter- A mixture of poultry excreta and bedding material such as sawdust, wood chips, peanut hulls, etc.

Slurry- A mixture of manure or litter with water to form a semi-liquid consistency.

Surface banding- Application method in which litter is dribbled onto the soil surface in bands 10-15 cm wide at 75 cm row spacing.