DETERMINATION OF AMMONIA EMISSION FACTORS FOR LAND APPLICATION OF POULTRY MANURE

by

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Abstract

The purpose of this project was to monitor ammonia emissions and develop updated ammonia emission factors for land application of poultry manure under British Columbia conditions. Field experiments were performed at the Agassiz Research Station in 2005 and 2006, which involved four types of poultry manure as the fertilizer materials and four varying heights of the grass canopy. Proceeding manure application, ammonia emission rates were determined using wind tunnels, the emitted ammonia captured using acid traps and analyzed with a flow injection analyzer. For all trials, the highest emissions occurred within the first day, and gradually declined over the next 2-3 weeks. Cumulative ammonia emission in all treatments did not exceed the initial amount of ammonia-nitrogen present in manure. Ammonia emission rates were significantly different among the manure types ($p < 0.005$). The percent total loss of ammonia with time was positively correlated with manure pH. Ammonia emission rates were generally higher in both of the spring trials than the fall trial. The ammonia-nitrogen emission rate was found to decrease as the grass height increase. The proposed revised ammonia emission factors of 0.12 and 0.16 kg-NH3-N/initial kg-N for the two major types of poultry – broiler and layer are in line with current emission factors adopted by Environment Canada. However, current and revised emission factors (0.38 versus 0.11 kg-NH3-N/initial kg-N) were substantially different for turkey manure.

TABLE OF CONTENTS

Abstract ii
TABLE OF CONTENTS iii
LIST OF TABLES iv
LIST OF FIGURES v
ACKNOWLEDGEMENTS vi
CHAPTER I - Introduction 1
1.1 Introduction 1
1.2 Aim and Scope of the Study 3
1.3 Organization of the Work 4
CHAPTER II – Literature Review 5
2.1 Ammonia Emission Inventory from Agriculture in Europe and USA 5
2.2 Current Canadian Emission Factors 7
2.3 Review of Field Trials for Land Application of Poultry Manure 7
CHAPTER III – Materials and Methods 12
3.1 Spring 2005 Trial 12
3.2 Summer 2005 Trial 14
3.3 Fall 2005 Trial 15
3.4 Spring 2006 Trial 15
CHAPTER IV – Results and Discussion 17
4.1 Spring 2005 Trial 17
4.2 Summer 2005 Trial 19
4.3 Fall 2005 Trial 24
4.4 Spring 2006 Trial 27
4.5 Effects of Temperature and Humidity 30
4.6 Ammonia Emission Factors 32
CHAPTER V – Conclusions and Recommendations 36
5.1 Conclusions 36
5.2 Recommendations 39
REFERENCES 40
Appendix A – Sample Calculations 43
Appendix B – Procedure of Analyses 47

LIST OF TABLES

Table 2.1 Summary of Environment Canada, European and USEPA Emission Factors................8

Table 3.1 Manure Analysis and Application Rates...16

Table 4.1 Change in net weight in orchard grass in relation to the change in height 20

Table 4.2 Daily ammonia emission rates associated with the land application of.........................24

Table 4.3 Cumulative percent total loss of ammonia over days 1, 2, 3 and 7...............................28

Table 4.4 Ammonia emitted as a fraction of various forms of initial nitrogen.............................34

Table 4.5 Comparison of current values and revised values of ammonia emission factors..........34

Table 4.6 Manure Analysis and Application Rates...35

LIST OF FIGURES

Figure 4.1 Ammonia emission rates for four types of poultry manure – spring 2005 trial............18

Figure 4.2 Percent ammonia emission – spring 2005 trial..18

Figure 4.3 Ammonia emission rates for four grass heights - summer 2005 trial...........................22

Figure 4.4 Percent ammonia emission – summer 2005 trial..22

Figure 4.5 Average wind speed profiles as a function of height from soil surface (July 13-14, 2005)..23

Figure 4.6 Average wind speed profiles as a function of height from soil surface (July 20, 2005) 23

Figure 4.7 Ammonia emission rates for the various types of poultry manure – fall 2005 trial 26

Figure 4.8 Percent ammonia emission – fall 2005 trial..26

Figure 4.9 Ammonia emission rates for the various types of poultry manure – spring 2006 trial 29

Figure 4.10 Percent ammonia emission – spring 2006 trial...29

Figure 4.11 Temperature measurements for the spring and fall trials..31

Figure 4.12 Relative humidity measurements for the spring and fall trials 31

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CHAPTER I - Introduction

1.1 Introduction

Ammonia (NH_3) emissions, being next to sulfur dioxide (SO_2) and nitrogen oxides (NO_x), are important contributors to the eutrophication and acidification of natural ecosystems. Its contribution to the formation of fine particulate matter and smog has also received increasing attention in recent years (Lefebvre et al. 2005). Concern about the role of ammonia as a precursor to environmental and health impacts led Environment Canada to declare ammonia as a toxic substance under the Canadian Environmental Protection Act (CEPA) in 2003. Ammonia is included in the international Gothenburg Protocol, which requires that all signatory nations quantify and reduce their emissions in relation to 1990 levels.

Ammonia emissions from farm operations have been identified by the National Agri-Environmental Health Analysis and Reporting Program (NAHARP) as one of the quantitative indicators of agricultural environmental performance in Canada. Based on current estimates, about 6% of all Canadian emissions can be attributed to land application of poultry manure. Poultry production in British Columbia constitutes some 15% of the total production in Canada, and the Fraser Valley of B.C. generates large quantities (approximately 280,000 tonnes) of poultry manure each year.

The ammonia found in poultry manure partially results from the uric acid produced as an end-product of nitrogen catabolic process; the uric acid decomposes into urea and finally ammonia. The ammonia enters the nitrogen cycle in its ionic form, ammonium $NH4^+$. It is oxygenated by nitrifying bacteria into nitrite in the soil, and then converted to nitrate in a process called nitrification. Ammonium ions readily bind to soils due to its positive charge. Nitrate and nitrite ions, due to their negative electric charge, bind less readily since there are less positively charged ion-exchange sites in the soil than negative sites. Leaching of nitrate and nitrite into groundwater can occur from precipitation or irrigation because of their solubility. Nitrites can be reduced to nitrogen gas through denitrification by anaerobic bacteria.

While land application of poultry manure can provide essential plant nutrients for crop production, improper manure management can lead to ammonia volatilization from the litter, and it can be detrimental to the environment. The deposition of ammonia in the natural ecosystem leads to eutrophication of lakes and rivers, and the nitrification of ammonia into nitrate, causing contamination of groundwater such as a regional aquifer. In the atmosphere, ammonia decomposition into nitrites and nitrates contributes to acid rain and the formation of ammonium-based particulate matter. Particles including ammonium nitrate and ammonium sulfate cause health problems such as chronic heart disease and lung cancer, and also account for 75% of the visibility impairments in the Lower Fraser Valley.

As an extension to the United Nations' 1979 Geneva Convention on long range trans-boundary air pollution, the International Gothenburg Protocol aims for the abatement of acidification, eutrophication and ground-level ozone. Signed on November 30th, 1999 by many European countries, one Asian country (Armenia), the USA and Canada, all signatory nations are required to reduce sulfur, NO_x, VOC and ammonia emission compared to 1990 levels.

The principle objective of this project is to monitor the seasonal variations of ammonia emissions from land application of poultry manure, in order to derive updated emission factors for the BC as well as ammonia indicator and inventory. These revised emission factors, which are defined as either "an emission percentage based on an initial mass present in the manure, expressed as mass of ammonia emitted per initial mass of ammonia nitrogen", or "an emission rate of ammonia per bird per year", will be compared to the emission factors currently adopted by Environment Canada (EC), and used as inputs to model atmospheric NH3 transport. The aim is to forecast how it reacts in the atmosphere to form aerial particles. The final results will be used to re-tool agricultural management practices and set goals for emission reductions.

This paper presents the findings from literature survey on ammonia emissions from arable land applied poultry manure, and ammonia emission results obtained from field experiments conducted during the spring, summer and fall periods of 2005, as well as spring 2006.

1.2 Aim and Scope of the Study

Earlier studies on ammonia emissions were largely concentrated on dairy and swine manure. Some research studies have been done on the ammonia emission from land application of poultry manure, but involve other variables including but not limited to manure incorporation, precipitation, and fertilizer pellets usage; very little has been done on turkey manure. Also, the grass canopy height on the effects of ammonia volatilization had never been addressed. Uric acid contents of various types of poultry manure have been measured in other studies; however, its effects on the ammonia release rate upon manure spreading have not been investigated. The emission factors currently adopted by Environment Canada contain certain assumptions and are not region-specific, and therefore, the development of an emission factor inventory in British Columbia would more accurately represent the ammonia emissions from land spreading of poultry manure in the province. A more controlled experimental atmosphere is desirable.

The goal of this thesis research is to observe the seasonal variation effects on the volatilization of ammonia from the land application of layer, broiler, breeder, and turkey manure. Specific objectives include:

1. To determine the ammonia emission factors in relation to the seasonal variation and poultry manure type;
2. To determine the relationship between ammonia volatilization and the height of grass on which manure is applied; and
3. To determine the uric acid content in manure and its contribution to the release rate of ammonia.

1.3 Organization of the Work

The thesis is contains 6 chapters. Chapter 1 is an introduction to the problems associated with ammonia emissions from the land application of poultry manure. The aim and scope of this study as well as the organization of the work are also presented in this chapter. Chapter 2 gives and in-depth literature review of previous ammonia inventory studies done in Europe and United States, the current Canadian inventory, and preceding trials on the application of poultry manure.

The emphasis of Chapter 3 is on the methodology utilized in the experiments. Chapter 4 discusses the results from the four trials performed, the effects of atmospheric conditions, and the ammonia emission factors obtained. Finally, the conclusions are presented in Chapter 5, summarizing the findings and recommendations.

CHAPTER II – Literature Review

2.1 Ammonia Emission Inventory from Agriculture in Europe and USA

Ammonia emission originates primarily from agricultural activities. Livestock production in Europe is the predominant source (70 to 90 percent of total emissions) followed by application of mineral N-fertilizers (up to 20 percent of total). The most recent inventories rely on country or region specific data on N-excretion and management practices. They distinguish between different manure systems to assess losses of nitrogen at the various stages of manure handling. This method is often referred to as "N-flow" or "process-based model" (Misslebrook et. al. 2000). It relies on the assessment of available nitrogen and NH_3-nitrogen at each considered stage (housing, storage, application) and its potential loss as ammonia. Recently, this method has gained wider acceptance, and has been used for the national ammonia emission inventories of the UK, Denmark, Germany, Netherlands, Switzerland and Norway (Kuczynski et. al. 2005).

After spreading of manure, the following factors play an important role in determining N-losses: meteorological conditions including temperature, humidity, turbulence, precipitation, soil properties including pH, calcium content, water content, manure properties such as pH, viscosity, dry matter content, the application rate, and the way manure is applied. The diet of poultry, type of poultry, the bedding as well as other additives to the manure litter dictates manure pH. The storage period allows for decomposition of the manure, which would also change the pH of the manure. The minimum information necessary to arrive at region-specific emission factors for each animal type includes typical N excretion rates, the manure application method, N-volatilization rates for different application practices. If emission factors during the manure application stage are based on N-excretion during the housing stage, it is necessary to know the N-volatilization rates during the housing stage, the manure storage stage and the manure application stage.

National inventories and projections for ammonia emissions in Austria, Germany and Ireland are compiled by using methodologies agreed upon by the Convention on Long Range Transboundary Air Pollution (CLRTAP) as set out in the Joint EMEP/CORINAIR Atmospheric Emission

Inventory Guidebook 2003. Emission factors of poultry manure from many European countries as well as the USEPA and Canada are shown in Table 2.1 below. This guidebook outlines a detailed method and a simple method for calculating these emission factors. The detailed methodology requires input data of animal numbers, nitrogen excretion, and manure management systems. Ammonia emissions from dairy cows, other cattle, fattening pigs and sows are estimated with the detailed methodology. In contrast, the simple methodology uses an average emission factor per animal for each livestock category and multiplies this factor by the number of animals counted in the annual agricultural census. Emissions from laying hens, broilers, other poultry, sheep, horses, and other farm animals are estimated using the simple method. There are problems with the simple method since there is no actual measurement data for most ammonia emitting activities (housing and storage). As well, uncertainties in emission values arise from oversimplified representations and related assumptions to quantify emissions in broad source categories. ECETOC (European Centre for Ecotoxicology and Toxicology of Chemicals) assigns emission factors as proportion of total N applied for each livestock type; for instance, 28.5% of total N was determined for cattle manure, 5.35% for pig manure, 37.6% for laying hens and 7.2% for broilers. However, EMEP/CORINAIR gives 20% of total N for manure from all livestock types. It is apparent that updated information on manure storage and manure management practices is necessary for improvements in the method currently used in estimating the emission factors.

In more recent documents (Kuczynski et al., 2005; USEPA, 2005), ammonia emission factors are given either in units of [percent initial total nitrogen or TN, %TN], or [kg NH3/animal/year]. USEPA suggested values of 42% TN for wet layer manure versus 7% TN for dry layer manure, whereas turkey manure is assumed to have the same value of 25% TN as broiler manure. By comparison, data from Norway indicated a range of 4% TN (spring) to 10% TN (autumn) for dry poultry manure. Ammonia emission factors, expressed in units of [kg NH_3/animal/year], are also available for total emissions from the combined activities of housing, storage and land application (for instance, in Austria, Czech Republic, Finland, Russia and USA). However, data for land application of poultry manure alone are very limited. USEPA adopted (2005) a single average value of 0.24 kg NH_3/animal/year for all types of poultry.

2.2 Current Canadian Emission Factors

For land application of poultry manure, the current Canadian emission factors are classified as "uncontrolled emission" and "controlled emission", and according to the types of poultry manure: pullets (< 19 weeks), laying hens (> 19 weeks), laying hens in hatchery supply flocks, broilers (and roasters and Cornish), turkeys and other poultry (including ducks and geese) (Environment Canada 2005).

Magnitudes of "uncontrolled emission factors" are based on the assumption that 50% of initial available N is volatilized as NH_3-N, and reported as the amount of NH_3 volatilized as [% TN]. In the category of emission factors associated with "controlled emission", expressed in units of [kg NH_3/animal/year], values currently adopted by Environment Canada are compatible with the European data for the various types of poultry manure. A summary and comparison of Canadian, European and US emission factors may be seen in Table 2.1.

2.3 Review of Field Trials for Land Application of Poultry Manure

Ammonia (NH_3) emission inventories are required for modeling atmospheric NH_3 transport and estimating downwind deposition. The derivation of the UK-based emission factors used in the calculation of that emission for a range of livestock classes, farm practices and fertilizer applications to agricultural land was described in (Misselbrook et. al. 2000). An emission factor of 45% UAN (uric and NH_3-N) content of the poultry manure was estimated from the results of field experiments. The average UAN content varies according to poultry type. A research study (Battye et. al. 2003) used poultry excretal output, among other livestock classes, for estimating the quantity of manure for land application. The researchers concluded that the slow conversion of uric acid to urea could lengthen the ammonia emission period. Ammonia emission factors from several European nations, USEPA and Environment Canada are presented in Table 2.1.

Table 2.1 Summary of Environment Canada, European and USEPA Emission Factors

	Emission factor, kg NH3/animal/year Based on total emissions (housing, storage, land application etc)			
	Layer	**Broiler**	**Turkey**	
Austria	0.22	0.17	0.54	Data not available for land application
Czech Republic	0.27	0.21	0.73	
Russia	0.37	0.28	0.92	
Finland	0.34	0.055	n/a	
Russia minus Austria	0.15	0.11	0.38	
Environment Canada	0.15	0.12	0.38	
USEPA	0.24 (composite value for all types of poultry)			2002 data (most recent)
	Emission factor, percent of TN Based on emissions during land application only			
Holland	19.5%	18.4%		Assuming TN in manure = 45% * TN in diet
ECETOC	37.6%	7.2%		
USEPA	42% (wet); 7% (dry)	25%	25%	Assuming turkey same as broiler's
EMEP/CORINAIR	20%			For all livestock types
Norway	4% (spring) to 10% (autumn)			For dry manure
*Huijsmans et al 2003	3.3 to 24% (highest in summer)			
*Rodhe and Karlsson 2002	13.5% (broiler)			

It is common practice amongst poultry farmers of the lower mainland to store manure in house or in storage throughout the year until a large quantity has been accumulated. Because farmers have to manage the large amounts of manure, or have fields that require large amounts of manure consistently, perennial grass such as orchard grass is ideal for its rate and amount of N uptake (Kaffka et. al. 1996). Also the variation in climate has minimal effect on the overall orchard grass growth and N uptake, meaning farmers can estimate the N uptake even with a range of possible conditions and manage nutrients to reduce undesirable N losses. Nitrogen uptake by orchard grass continues throughout the growing season and not just the first growth cycle, allowing for multiple experiments with longer durations. A diurnal rhythm of emission was evident with higher emission during the day and lower emission at night (Wulf et. al. 2002); this can be attributed to temperature effects on NH3 solubility and the equilibrium concentration of NH3 and NH4+ according to Henry's law.

There are guidelines on the poultry manure application rates for different vegetable crops, grass and cereals (British Columbia Ministry of Agriculture, Fisheries and Food. 1997). The application rates are usually based on nitrogen (typical nitrogen uptake by the plants in kg/ha), if excess phosphorus and potassium do not cause environmental concerns. Because this study is focused on ammonia emission from land applied manure, the application rate follows the nitrogen-based application guidelines for perennial crops such as orchard grass. It depends on the moisture content and nitrogen content of manure; greater application rates are required if moisture content is higher and nitrogen content is lower.

A series of experiments were conducted using small wind tunnels to assess the influence of a range of environmental, manure and management variables on ammonia emissions following application of different manure types to grassland and arable land (both to stubble and growing cereal crops), in keeping with common practice in the UK (Goebes et. al. 2003). Wind speeds through the tunnel canopies were controlled at 1 m s^{-1}. The concentration of NH_3–N in both the air entering and leaving each tunnel was determined by drawing a sub-sample of air (at 3–4 l min^{-1}) through absorption flasks containing phosphoric acid. Measurements of NH_3 emission continued for 12 d following solid manure applications. In addition to NH_3 emissions, measurements were also made of manure dry matter (DM) content, pH, total N content, total

NH3-N (TAN) content and uric acid N content, plus soil moisture content and soil pH (top 10 cm), crop height (and growth stage for cereals), wind speed (at a height of 25 cm), air and soil temperatures (at 5 cm height and 5 cm depth, respectively) for each experiment. Differences in temperature were achieved by applying manure at different times of year. For solid manures, rainfall was identified as the parameter with most influence on ammonia emissions by leaching into the soil matrix thence the local aquifer.

A multi-season study was conducted to quantify NH_3 volatilization rates from surface-applied poultry litter under no-till and plowed conservation tillage managements (Huijsmans et. al. 2003). Litter was applied to supply 90 to 140 kg N ha^{-1}. Poultry litter was applied immediately after planting and before seed germination, with the standing stubble from the previous crop being 10 to 15 cm tall. Micrometeorological data and atmospheric NH_3 concentrations were determined 24 to 48 h before litter application and for 7 to 8 d following applications. Results showed that ammonia volatilization was rapid immediately after litter application and stopped in about a week. Total losses of NH_3 from surface-applied poultry litter ranged from 3.3 to 24% of the total N applied with the largest losses under summer (hot, dry, windy) conditions. Losses of 22 to 24% would be large enough to potentially decrease crop yields when 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. Precipitation (rainfall) of 17 mm within 48 h of application greatly inhibited volatilization rates, probably by transporting litter N into the soil matrix, although 36 to 64% of the ammonia 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 but could also increase NO_3 leaching and runoff to streams and rivers.

A spreading experiment was conducted at Ultuna, 5 km south of Uppsala, Sweden. After storage, broiler manure and commercial fertilizer pellets (a mixture of broiler manure, harvest residues and stone meal) were spread to arable land at a rate of 110 kg [total-N] ha^{-1} (Misselbrook et. al. 2005), which corresponds to a rate of 4.4 t broiler manure per hectare and 2.7 t pellets per hectare. The broiler manure was applied with a spreader JF, type ST70-H, modified as a two-step spreader. The soil had a texture classified as clay and 2-3% organic matter. The treatments were arranged as a randomized block design with three replicates. Ammonia emissions were measured from plots fertilized with broiler manure and pellets, respectively, with and without harrowing 4 h after spreading. For plots fertilized with broiler manure with no incorporation of the manure into the soil, the NH_3 emissions were measured on five occasions over a period of 5 days and for plots fertilized by broiler manure and harrowed 4 h after spreading on three occasions during 2 days. The pellets were also applied plots, with and without incorporation. Totally, 13.5% of the nitrogen in the broiler manure was lost as ammonia after spreading without-incorporation of the manure and 7.5% from plots with incorporation. After incorporation no ammonia emission occurred. No emissions occurred from plots fertilized with pellets. Incorporation after spreading of broiler manure was found to be an effective way to reduce ammonia emissions. The incorporation should be carried out as soon as possible after spreading, or at least not more than 4 h after spreading, to limit the ammonia losses to about half of the potential amount.

Based on a project specific to broiler litter and layer manure (Anon 2003), where manure was applied to land at a target rate of 250 kg N/ha (though actual rates varied from 120 to 470 kg N/ha), research findings indicated there were no differences in emissions between any of the broiler litter treatments following land spreading, with total ammonia losses equivalent to 46-92% (average 63%) of the UAN applied over the 28 day measurement periods. Likewise, there were no differences in emissions following land spreading between the various layer manure removal methods or between layer manures from the different commercial unit houses. Total ammonia losses were equivalent to 67-118% of the UAN applied over the same period; however, no explanation was given as to how losses could possibly exceed 100%.

CHAPTER III – Materials and Methods

3.1 Spring 2005 Trial

Field tests were performed at the Agassiz Research Station of the Pacific Agricultural Research Center (PARC) in May-June 2005 using four different types of poultry manure (breeder, broiler, layer, and turkey) as the fertilizer materials. The manure was collected from commercial poultry farms within the Fraser Valley of B.C. for this trial, as well as for the summer 2005, fall 2005 and spring 2006 trials. The various types of manure were either fresh from housing, had been stored in-barn, or as a covered-pile outdoor. After manure application, wind tunnel canopies were positioned over each plot with air drawn through at a constant and controlled rate. Sixteen framed wind tunnels were installed for the experiments, with the frames set 50 mm in the ground. Polycarbonate covers were secured on the frames immediately after manure application. Each tunnel has the general height of is 450 mm and a width of 500 mm. A rotary anemometer was mounted inside the blower unit of each tunnel, with an orientation perpendicular to airflow. Airflow rates from the anemometers inside the tunnels were transmitted to a multiplexer and a CR10X data-logger via a signal transmitter box. Four of the 16 anemometers contained temperature probes which monitored ambient temperature within the tunnel. This data was also transmitted to the CR10X data-logger. Data were downloaded periodically from the data-logger onto a laptop computer.

Air sample inlet for the tunnel was located above the blower. Acid traps were set up using graduating cylinders containing 100 ml of 0.01 M phosphoric acid to capture ammonia from the sample. With suction from a pump, a sub-sample of tunnel air (at 2-3 L/min) was bubbled through the acid solution via a Tygon tube placed at the inlet of each tunnel and the inlet of the blower. Each unit was connected to an Erlenmeyer flask to capture condensate. Flow restrictors were used to reduce the load on the pump. The volume of air sampled was measured using flow meters. All equipments were placed inside weatherproof wooden boxes. The wind tunnel method and ammonia capture technique used in this study is similar to that used by Misselbrook et al. [1].

On the first day when the rate of NH_3 volatilization was anticipated to be highest, the acid traps were changed and replenished at time intervals of 1 h, 2 h, and 5 h following manure application.

Thereafter, 1-2 shift changes occurred in the morning and mid-afternoon for 8 days, and once a day after that until Day 21. A total of 32 liquid samples (2 bubblers per tunnel) obtained from each acid change shift were stored in a cooler at 5°C. Samples were prepared for analysis by filling the liquid levels to 120 ml if the bottles should contain fewer amounts due to field evaporation of the acid solution as a result of heat from the environment and the pumps inside the boxes. Once prepared, they were analyzed using a flow injection analyzer (FIA). The amount of NH_3 volatilized during each interval was calculated from the amount of NH_3 trapped and the airflow data.

A randomized complete block design was adopted for the experiment, with 4 treatments for the various types of poultry manure having 4 replicates for each treatment. Preceding application, manure samples were analyzed for moisture content, ammonia-nitrogen, and total nitrogen contents; pH values were also measured for the spring and fall 2005 manure samples. Material balance on N was not done for this study because ammonia emission was the main concern; hence, leachate or runoff was not measured. The total nitrogen content of the manure is important for the determination of its fertilizer value. Proximate analyses included manure pH and moisture content and elemental analyses consisted of total nitrogen (TN) and total ammoniacal nitrogen (TAN) contents. The C:N ratio was not measured because the manure was used directly as fertilizer, rather than for composting purposes. Other elemental analyses were not analyzed because they would have little or no effects on ammonia volatilization. Other proximate analyses such as ash or electrical conductivity were not measured because they are not important information for land application of manure. Based on these analyses, manure was surface-applied by hand to the plots (0.5 × 2 m). In the spring and summer trials, the quantity of manure applied as shown in Table 3.1 was based on ammonia-nitrogen, which is equivalent to 100 kg NH4-N/ha or 470 kg N/ha, respectively. In the fall trial, the application rate was based on total-N. Measurements of NH_3 emission continued for 21 days following manure application.

Using the data associated with the sub-sample of tunnel airflow during each shift change, and assuming that ammonia capture rate is equal to the ammonia emission rate, the latter was computed from the trapped ammonia concentration values. The ammonia emission rate from the entire plot was then computed using the ratio of actual airflow rate (from the rotary anemometer readings) to the sub-sample airflow rate. Thus,

$$E = (C_o - C_i)\, V\, R \qquad \text{Eqn. 1}$$

Where E is ammonia emission rate based on sub-sample tunnel air, [mg per interval]; C_o is concentration of ammonia at blower intake; C_i is concentration of ammonia at tunnel intake; V is volume of acid trap solution; R is the ratio of actual airflow rate to the sub-sample airflow rate = $v A/Q$; v is rotary anemometer speed anemometer wind speed; A is tunnel cross sectional area, and Q is sub-sample tunnel flow rate tunnel flow rate These calculations were performed for all shifts of all tunnels.

3.2 Summer 2005 Trial

The trial was performed in July 2005 using broiler manure as the fertilizer material. The experimental setup was essentially the same as that of the spring trial except the treatments comprised of 4 heights of orchard grass (low 25 mm, medium-low 75 mm, medium-high 175 mm, and high 275 mm) with 4 replicates for each treatment. Manure was surface applied to the plots (0.5 × 2 m) by hand at a rate of 2.79 kg per tunnel or per m^2, the same as that used for the spring trial

Prior to spreading broiler manure onto the plot, four different grass heights were cut to study the effects of canopy height on ammonia emission. A lawn mower was used to cut the shortest two heights, which came out to average grass heights of 25 mm and 75 mm, respectively. The third height was trimmed using shears with a piece of wood used as a height reference; the average height came out to 175 mm. Uncut grass was used as the final and tallest canopy with an average of 275 mm.

The effect of turbulence was observed from the four different heights of grass. A hot wire anemometer was inserted through three holes drilled into the polycarbonate canopy cover of each wind tunnel to measure the varying wind profiles. A total of 15 points were collected for each hole, where each point is an average of 5 wind velocity reading from the hot wire anemometer.

The average values between replicates were used to demonstrate the average wind profile for each treatment.

3.3 Fall 2005 Trial

Field tests were performed at in November-December 2005 using poultry manure as the fertilizer materials. A randomized complete block design was used for the experiment, with 4 treatments for the various types of poultry manure and 4 replicates for each treatment. Manure was surface applied to the plots (0.5 × 2 m) by hand after weighing out specific amounts. The initial amounts of manure applied are also reported in Table 3.1, and the application rate is based on 150 kg N/ha. Measurements of NH_3 emission continued for 21 d following manure applications.

After the experiment, Tygon lines running from the acid bubbler to the overflow cylinder and the overflow cylinder itself were washed with acid. This acid washing fluid sample was collected to measure any residual ammonia that may have been trapped in the lines or in the overflow as condensate. As well, manure scrapings were collected from each treatment plot to be analyzed again for ammonia-nitrogen content.

3.4 Spring 2006 Trial

Field tests were performed at Agassiz Research Station of PARC in April 2006 using poultry manure as the fertilizer materials. A randomized complete block design was used for the experiment, with 4 treatments for the various types of poultry manure and 4 replicates for each treatment. Manure was surface applied to the plots (0.5 × 2 m) by hand after weighing out specific amounts. The initial amounts of manure applied are reported in Table 3.1, and the application rate is based on 150 kg N/ha, which is same as the previous trial in the fall. Like the spring 2005 trial, both the moisture content and ammonia nitrogen content of layer manure were greater than those of the other three types of manure.

Based on the daily ammonia emission rates, ammonia emission was calculated as a fraction of the initial amount of ammonium-N present in applied manure. These values were then multiplied by the ratio of "ammonium nitrogen-to-total nitrogen" (NH4:TN), and the ratio of "ammonium nitrogen-to-uric acid and ammonium nitrogen" (NH4:UAN), in turn, to obtain seasonal emission factors. Statistical analysis of the ammonia emission results over 2 days, 7 days and the end of each trial period (2-3 weeks) was performed via the analysis of variance (ANOVA), which is a collection of statistical models. If the overall "p value" from the ANOVA is small, for example $p < 0.005$, it means it is unlikely the differences observed are due to random sampling, and that there is significant differences between treatments.

Table 3.1 Manure Analysis and Application Rates

Type of manure	Application rate, kg/m^2	Moisture content, % w.b.	Total nitrogen, % d.b.	Ammonia-N, % d.b.	NH3:TN	pH
Spring 2005 Manure Types Trial						
breeder	2.08	33.3	2.98	0.72	0.24	8.4
broiler	2.79	36.7	2.67	0.57	0.21	8.5
layer	1.26	79.5	6.26	3.88	0.62	6.5
turkey	0.74	41.6	7.35	2.33	0.32	8.4
Summer 2005 Grass Heights Trial						
broiler	2.79	36.7	2.67	0.57	0.21	8.1
Fall 2005 Manure Types Trial						
breeder	0.56	23.0	2.89	1.22	0.42	8.8
broiler	0.68	32.1	3.06	0.52	0.17	8.9
layer	0.30	13.4	5.90	0.82	0.14	7.9
turkey	0.30	29.0	7.53	1.84	0.24	5.9
Spring 2006 Manure Types Trial						
breeder	0.52	31.7	4.26	1.20	0.28	7.3
broiler	0.41	22.1	4.73	0.90	0.19	7.5
layer	0.71	53.7	4.55	2.53	0.56	7.3
turkey	0.36	29.6	5.95	1.26	0.21	6.7

w.b.: wet basis
d.b.: dry basis

CHAPTER IV – Results and Discussion

4.1 Spring 2005 Trial

From the data associated with the sub-sample of tunnel airflow during each shift change, and assuming the ammonia capture rate is equal to ammonia emission rate, the hourly and hence daily ammonia emission rates were computed from the trapped ammonia concentration values. Results are shown in Figure 4.1 with the standard error bars that represent a 95% confidence interval. The manure exhibited emission results as expected, with the highest emissions at 1400, 2600, 800 and 1200 mg/d for breeder, broiler, layer and turkey manure, respectively, occurring within the first day then gradually decreasing in the 16-day period of measurements proceeding manure application, although zero emission was not achieved. Based on these results, the total amount of ammonia emitted over the monitored period was estimated and expressed in terms of the initial ammonia-nitrogen content of the manure, as depicted in Figure 4.2. Cumulative ammonia emission in all treatments did not exceed the initial amount of ammonia-nitrogen present in manure. Total ammonia emissions were significantly different between the manure types ($p < 0.005$).

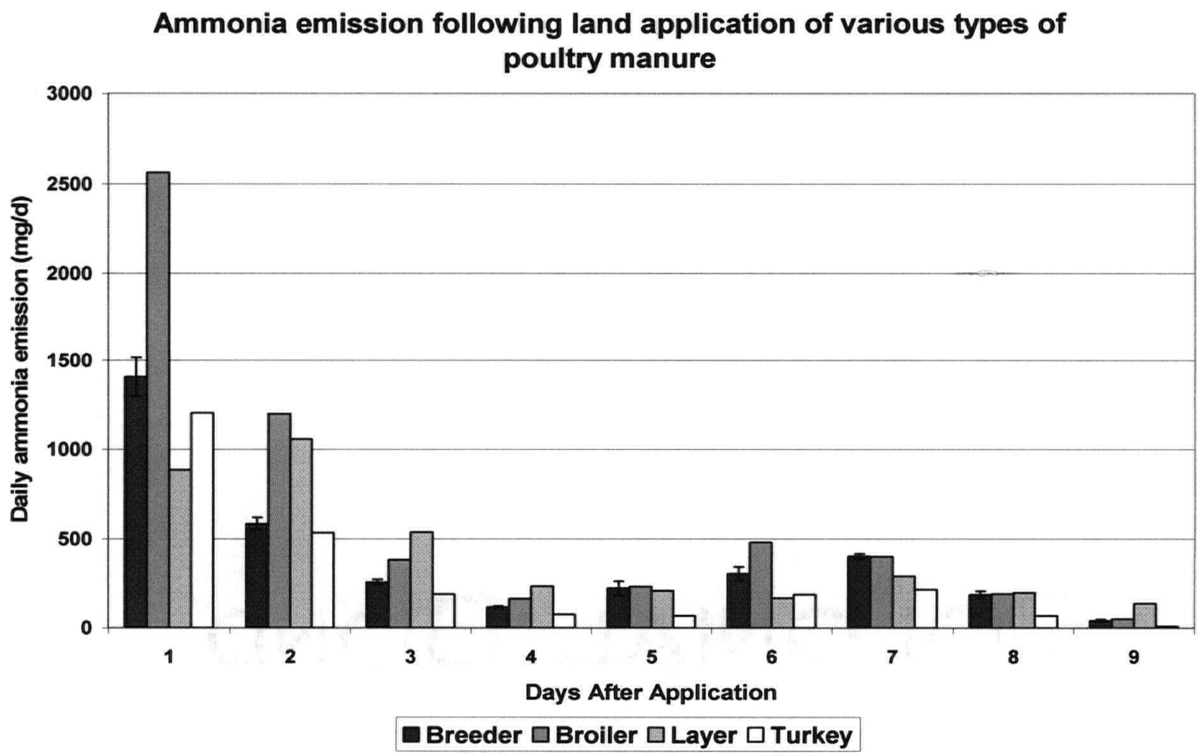

Figure 4.1 Ammonia emission rates for four types of poultry manure – spring 2005 trial

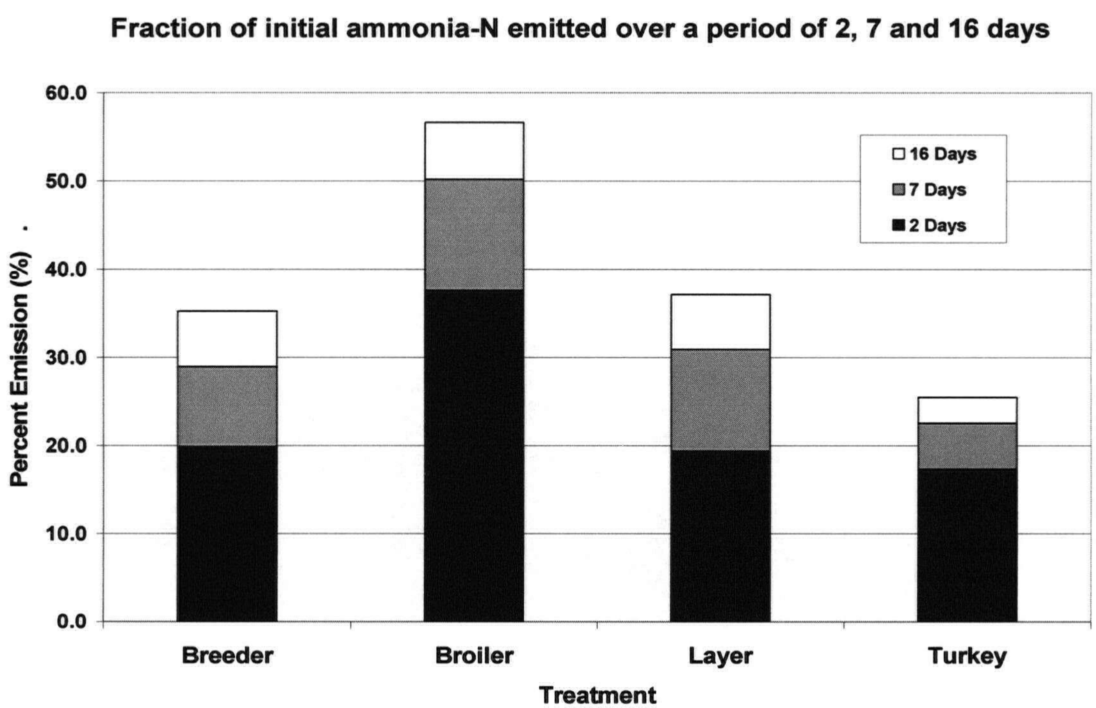

Figure 4.2 Percent ammonia emission – spring 2005 trial

4.2 Summer 2005 Trial

The profiles of ammonia emissions over 14 days are shown in Figure 4.3 for the four orchard grass heights, with standard error bars (95% confidence) indicating the variation due to the replicates. The general ammonia emission trend was similar for all treatments. The NH_3 volatilization rate from applied manure was rapid immediately (day 1) after manure application and declined with time, as expected. Ammonia emissions were consistently-higher for the low (25 mm) and medium low (75 mm) grass heights, whereas the lowest emission was associated with the high (275 mm) grass. The wind speed collectively with taller grass canopy was able to take up more NH_3-nitrogen form the manure. Nevertheless, ANOVA results showed the total NH_3 emissions over the 2-week period were not significantly different ($p > 0.10$) between the grass heights.

As shown in Figure 4.4, losses of ammonia during this period amounted to 65%, 60%, 56% and 43% of the initial ammonia-N for the orchard grass heights of 25 mm low grass, 100 mm medium-low grass, 175 mm medium-high grass and 275 mm high grass, respectively. When compared to the initial amount of total N in the broiler manure, such losses ranged from 9.1 to 13.9%. This is in good agreement with results obtained by Rodhe and Karlsson (2002), (13.5% of the nitrogen in the broiler manure was lost as ammonia over the first 5-day period), for plots fertilized with broiler manure with no incorporation. It is also in the same order of magnitude (3.3 to 24%) as reported by Sharpe et al. (2004), who considered losses of 22 to 24% to be large enough to potentially decrease crop yields when poultry litter is used as the sole source of N fertilizer and applications are based on the N content of the litter. According to Fulhage and Pfost (1994), until poultry manure is incorporated into the soil, its ammonia-N losses generally ranged from 20% within two days of application, to 80% after 7 days of application; in other words, only 20% of initially applied ammonia-N is available for crops if it took more than 7 days till incorporation.

There are two hypotheses that could explain the lower ammonia emissions from taller grass in comparison to higher emissions from shorter grass: either the taller grass has the ability to uptake more nitrogen from the manure, or the taller grass resulted in less turbulence at the soil-manure interface. The height of the grass is directly related to the depth of the root system; because the grass initially for all treatments was the same height before trimming, and manure application was immediately following grass trimming, the root system should be the same at the start of the trial. In general, taller grass is able to uptake a larger amount of nitrogen and has more surface area to harvest light energy to use for growing roots for nitrogen uptake, and for growth. Therefore, the uptake of nitrogen from the manure to the grass is greater for taller grass. In addition, the shorter grass may have taken less nitrogen as a result of the amount trimmed from the grass. A general rule for lawn maintenance is to cut no more than a third of the grass in order to not stress the plant. As a result of the extensive trimming, the plant loses its photosynthetic ability causing root death. The change in nitrogen of the orchard grass and the change in grass height can be seen in Table 4.1. A positive correlation can be seen between the initial grass height and the ratio between the changes in the net weight to the changes in grass height.

Table 4.1 Change in net weight in orchard grass in relation to the change in height

Trt	ΔNW, g	St Dev	ΔGH, inches	ΔNW /ΔGH
LO	0.97	0.23	12.1	0.080
ML	1.42	0.16	13.0	0.109
MH	1.65	0.18	10.1	0.163
HI	1.37	0.19	7.5	0.183

It is also very likely the taller grass canopy created a boundary layer which reduced the air flow below the canopy, increasing flow through the upper portion of the wind tunnel. With taller grass, the resistance of air flowing through the grass increases due to a denser canopy; with the air flowing through each wind tunnel conserved, this forces air to flow above the grass canopy. The turbulence decreases at the manure-air interface as a result of lower air flow rate, consequently reducing the flux of ammonia between the air and manure.

Higher air velocities at the ground-air interface could have promoted more air mixing within this zone, thus increasing the diffusion of ammonia, lowering the NH_3 concentration in the air above the manure, and eventually stimulating further NH_3 volatilization. This relationship between wind speed and ammonia volatilization explains why the most emissions were seen in the low grass (higher wind speeds). In this aspect, Huijsmans et al. (2003) had observed that wind speed exerted a substantial effect on the volatilization rate, only when manure was surface applied or surface incorporated. It can be seen in Figure 4.3 that there is very little difference in ammonia emission between the medium low and low grass throughout the trial. On the first day, it is very evident the highest grass resulted in the lowest emissions, followed by the medium high grass. Moreover, the high grass emitted over 1000 mg less than medium low and low grass on the first day immediately following application, and remained the treatment with the lowest emission for the first 7 days. While the growth of grass is greatest for the lower grass-heights, the emission rate remains the highest. Therefore, it is more likely that the differences between the ammonia emission rate is related to the wind speeds at and near the soil-manure interface as oppose to the uptake of ammonia by the grass.

Examination of the rotary anemometer readings indicated that the measured data were relatively constant for all tunnels during the field test period; however, they were different among the treatments, for instance, the average reading was 11.78±0.31 m/s for the medium low grass height, whereas it was 14.23±0.06 m/s for the low grass height.

The wind speed profiles derived from the hot wire anemometer measurements on two occasions are shown in Figures 4.5 and 4.6. Air velocity is seen to increase with height from the soil surface; moreover, as grass height increases, the difference in air velocity between treatments increases in the zone 20-40 cm above the soil surface, this relationship being most pronounced for the high grass. This relationship is a result of the wind speed being conserved within the tunnel; that is, lower wind speeds within the grass canopy are associated with relatively higher wind speeds within the upper region of the tunnel.

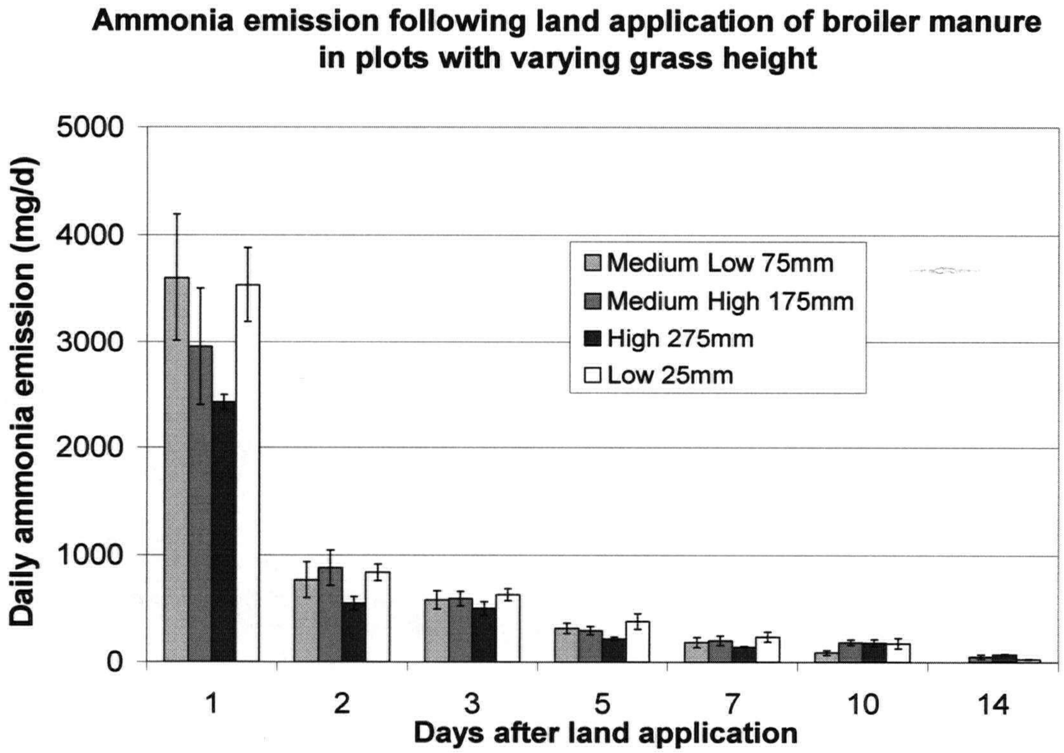

Figure 4.3 Ammonia emission rates for four grass heights - summer 2005 trial

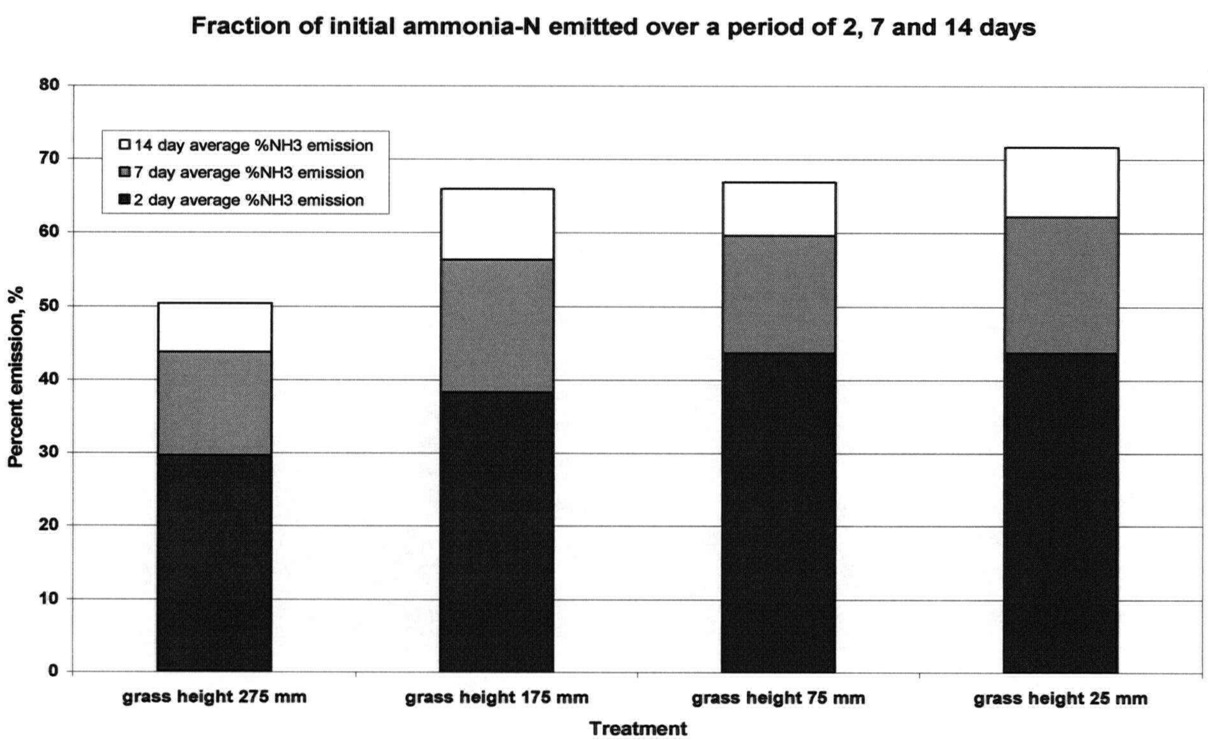

Figure 4.4 Percent ammonia emission – summer 2005 trial

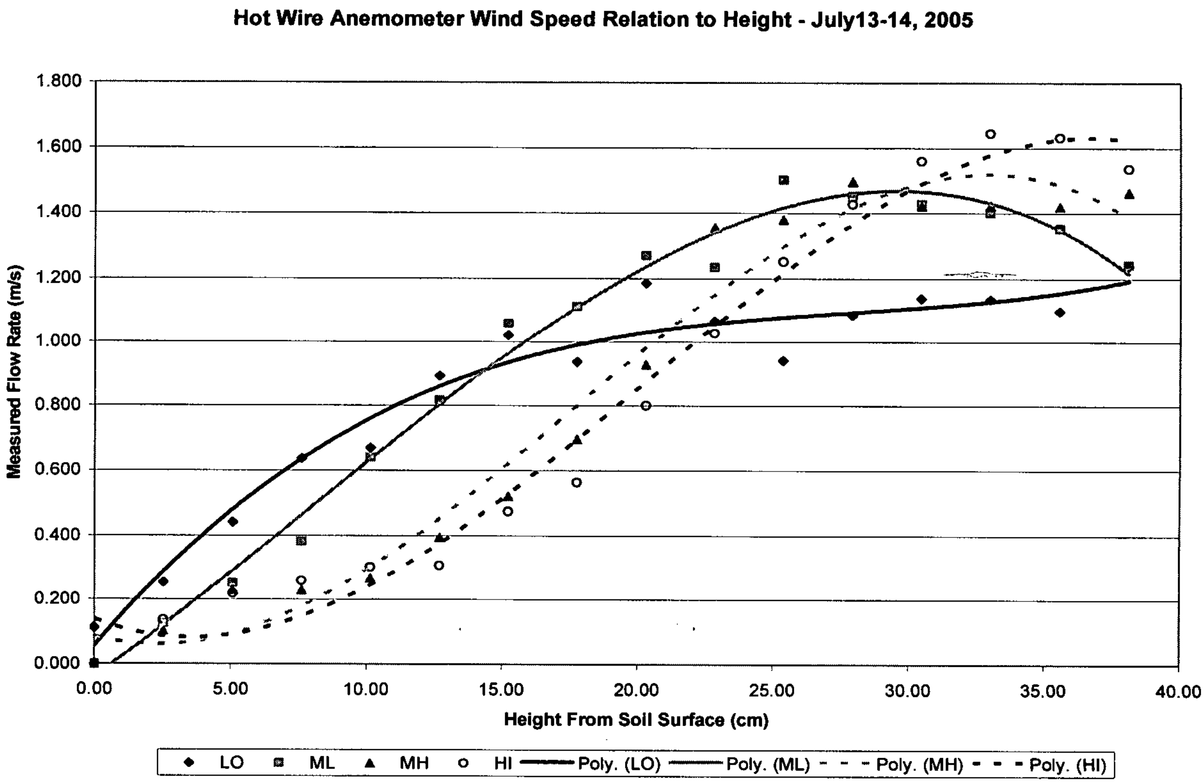

Figure 4.5 Average wind speed profiles as a function of height from soil surface (July 13-14, 2005)

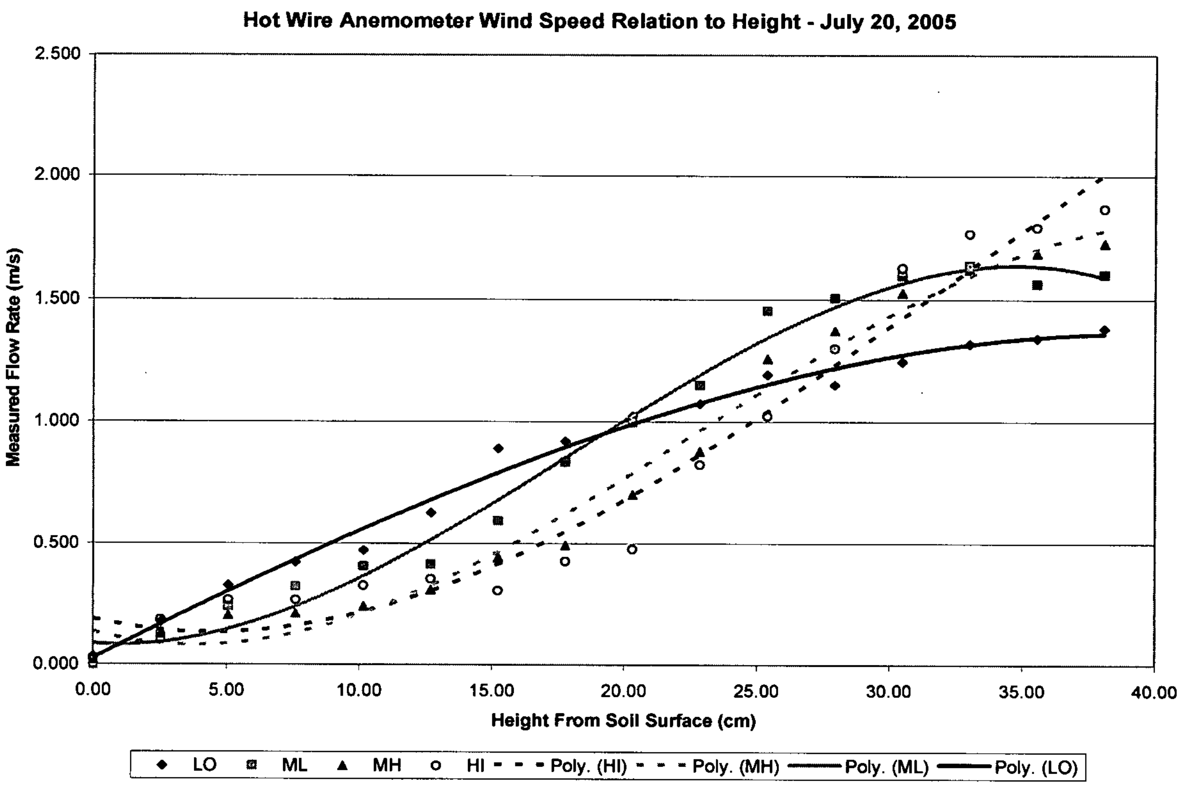

Figure 4.6 Average wind speed profiles as a function of height from soil surface (July 20, 2005)

4.3 Fall 2005 Trial

As shown in Table 3.1, the initial layer manure ammonia content was significantly less for the fall 2005 trial (0.82%) than that for the spring 2005 trial (3.88%). The manure from the spring trial was observed to be very wet and thus trapped more ammonia, which could explain the higher percent of initial ammonia content. Since the layer manure samples from the fall trial were collected from stored manure piles, it is possible that the manure had gone through a passive composting process entailing to the loss of ammonia nitrogen. In contrast, the breeder and broiler manure samples were collected from fresh manure piles for both trials with similar initial ammonia contents.

Results obtained from averaging of the four replicates in each treatment are shown in Table 4.2; similar emission pattern to the spring 2005 trial was evident in the fall 2005 trial (Figure 4.7), with the standard error (SE) bars that represent a 95% confidence interval (CI) for the data. The ammonia emissions were significantly different ($p < 0.001$) between the various types of poultry manure over the trial period of 21 days after land application. Although they varied in the bulk amount of emissions over the 21 day period, all four types of poultry manure exhibited similar patterns of emissions with the most ammonia being emitted over the first few days and tapering off thereafter, as expected.

Table 4.2 Daily ammonia emission rates associated with the land application of the four types of poultry manure – fall trial

Days after land spreading	Ammonia Emission Rate, mg/d			
	Breeder	Broiler	Layer	Turkey
1	1005	654	449	234
2	175	195	77	62
7	23	28	9	21
14	19	22	15	12
21	9	3	8	5

After 21 days, there were no observed differences in grass heights between the treatments, or between the plot areas versus outside grass area. Analysis of grass samples also confirmed that the differential uptake of ammonia nitrogen by the grass is negligible.

The ammonia emission rates were then expressed as a fraction of the initial amount of ammonia-nitrogen present in the manure, as demonstrated in Figure 4.8. These profiles suggested that the percent ammonia emissions were significantly different ($p < 0.001$) between the various types of poultry manure 2, 7 and 21 days after land application. After the first two days, breeder manure emitted the most emissions (54%), followed by broiler (41%), layer (26%), and then turkey (20%). This trend is consistent until the end of the trial on day 21; breeder manure had emitted the most emissions (85%), followed by broiler (70%), layer (40%) and turkey (26%). The lower percent ammonia emission of layer manure and turkey manure could be partially attributed to the characteristics of the manure at collection. There is a positive correlation between ammonia emission and pH ($r = 0.86$), while ammonia emission is again negatively correlated with TN ($r = -0.92$) for the first 5 hours after land application. Hence, the lower percent ammonia emission from layer and turkey manure could be partially attributed to the pH of the manure at time of application; breeder and broiler manure had a pH around 8.8, compared to layer and turkey manure was 7.9 and 5.9, respectively. The pH affects the equilibrium of $NH4^+$ and NH3. Specifically, the increase in pH increases the concentration of ammonia, allowing for greater volatilization. However, the release of ammonia from the manure increases the acidity by shifting the equilibrium from ammonium ion to ammonia, in turn slowing the release rate of ammonia.

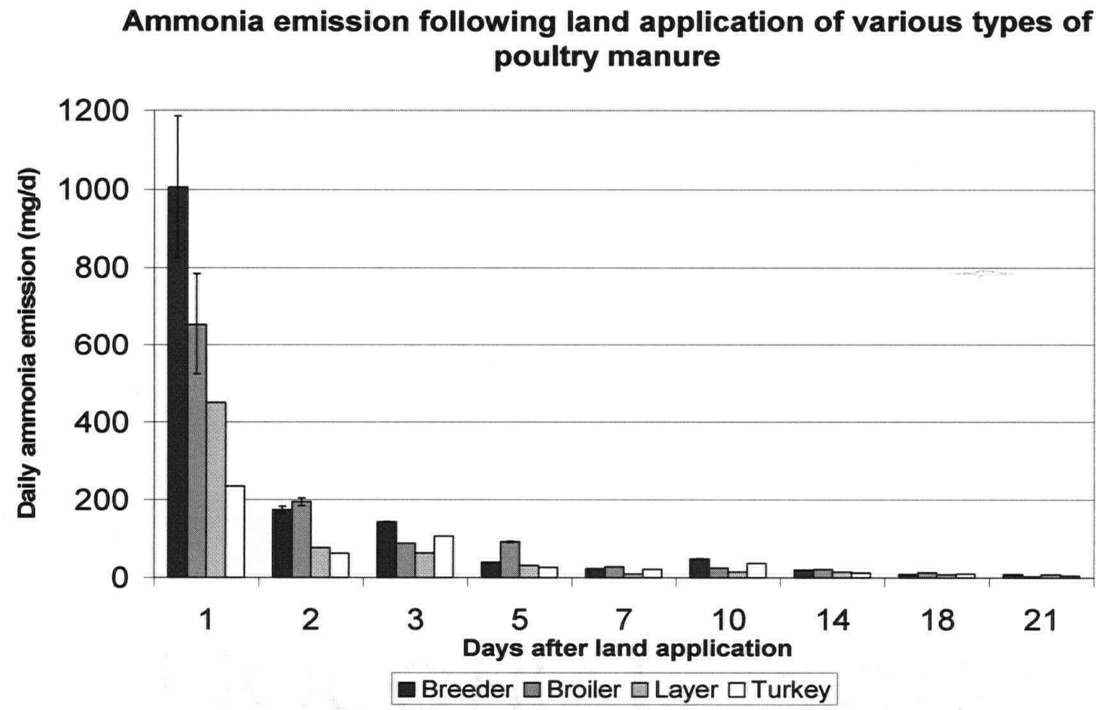

Figure 4.7 Ammonia emission rates for the various types of poultry manure – fall 2005 trial

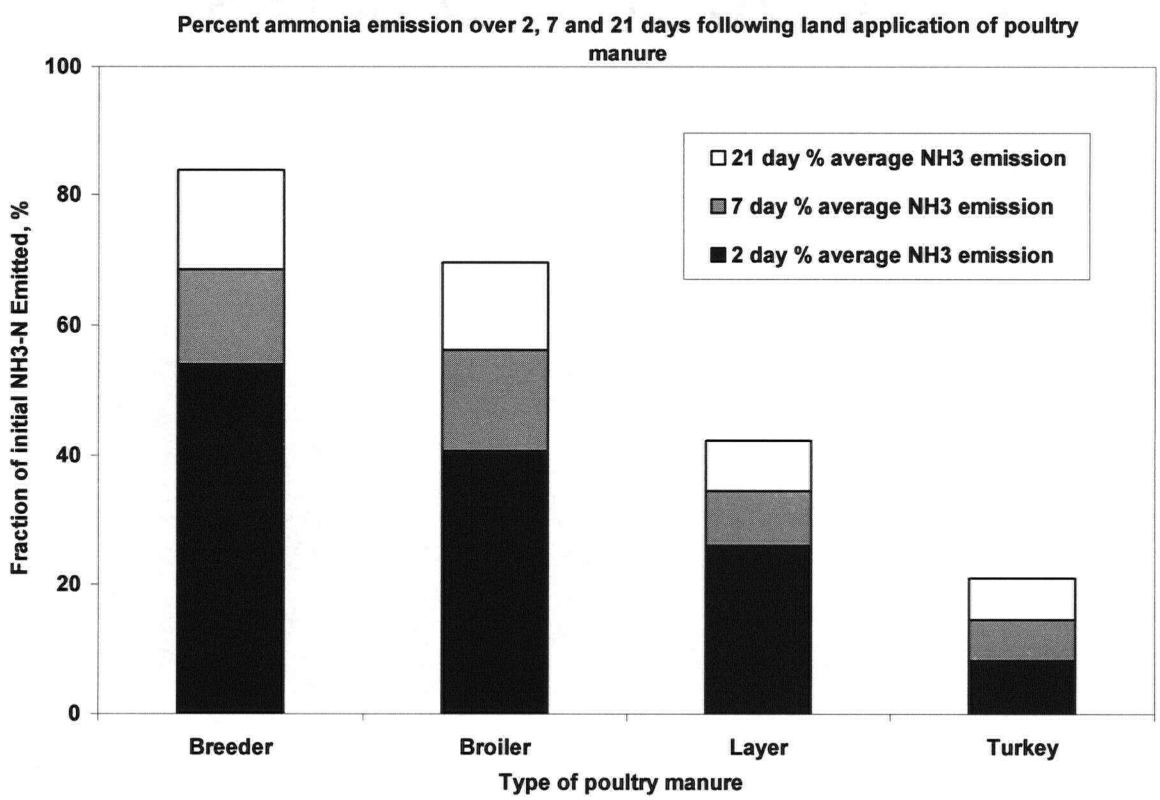

Figure 4.8 Percent ammonia emission – fall 2005 trial

4.4 Spring 2006 Trial

As depicted in Figure 4.9, a similar temporal pattern of emissions was again apparent for the spring 2006 trial. Unlike the previous trials, turkey manure exhibited a significantly different ammonia emission pattern with a loss less than 20% ammonia during the first three days, with peak emission rate of 220 mg d^{-1} m^{-2} on day 1; subsequently emission declined but then rose to 600 mg d^{-1} m^{-2} towards the end of the 3-week trial period. This phenomenon is in contrast to other manure types, with most ammonia being emitted over the first few days and tapering off thereafter. The relatively low emissions of turkey manure in the first 3 days in the fall 2005 and spring 2006 trials may be due to its lower manure pH. In the 2006 trial, emission from turkey manure exceeded the other manures on days 16 and 22, probably due to release of ammonia, which might have been accelerated if the manure had been moistened. Other manures tended to have higher pH favoring early release of ammonia. The percent ammonia emissions relative to the initial amount of NH_3-N present in manure were significantly different ($p < 0.001$), between the various types of poultry manure 2, 8 and 22 days after land application.

The ammonia emission rates were then expressed as a fraction of the initial amount of ammonia-nitrogen present in the manure, as demonstrated in Figure 4.10. The percent ammonia emissions relative to the initial amount of NH_3-N present in manure were significantly different ($p < 0.001$), between the various types of poultry manure 2, 8 and 22 days after land application.

A summary of the cumulative percent total loss of NH_3 (relative to total loss at the end of the trial period) after 1, 2, 3 and 7 days after manure application is presented in Table 4.2 Such information would be useful in guiding the timing and abatement value of incorporating manure after spreading. On average, the ammonia losses on day 1 were 48%, 41%, 38% and 29% for breeder, broiler, layer and turkey manure, respectively; and by day 7, the cumulative total ammonia losses reached 83%, 81%, 80% and 67% for these four types of manure. Rodhe and Karlsson (2002) found that incorporation within 4 hours of manure spreading could cut ammonia losses by 50%. Chambers et al. (1999) had also pointed out that rapid incorporation of the manures following land spreading would reduce ammonia emissions by 35-63%.

Table 4.3 Cumulative percent total loss of ammonia over days 1, 2, 3 and 7 after the land application of manure

Type of manure	Day 1, % total loss	Day 2, % total loss	Day 3, % total loss	Day 7, % total loss
Spring 2005 Trial (manure types)/ Summer 2005 Trial (grass heights)				
breeder	40	57	64	82
broiler spring summer	45 45-54	66 56-66	73 65-75	89 82-90
layer	24	52	67	83
turkey	47	68	76	89
Fall 2005 Trial				
breeder	52	66	74	83
broiler	42	61	67	82
layer	50	63	70	82
turkey	30	41	55	70
Spring 2006 Trial				
breeder	53	64	69	83
broiler	36	44	50	72
layer	39	52	58	76
turkey	11	14	18	42

It should be noted that the turkey manure used in all trials of this project had higher nitrogen contents (6.0-7.5% d.b.) than previously reported (4.0-5.0% d.b.) by the BC Sustainable Poultry Farming Group (BCMAFF 1997). In contrast, the measured nitrogen contents of other manure types (breeder, broiler and layer) were similar to the previously reported values. Ultimately, the freshness of the manure is measured by the TN, TAN and moisture content; for manure that has been kept in storage over a long period, its TN, TAN and moisture will be lower.

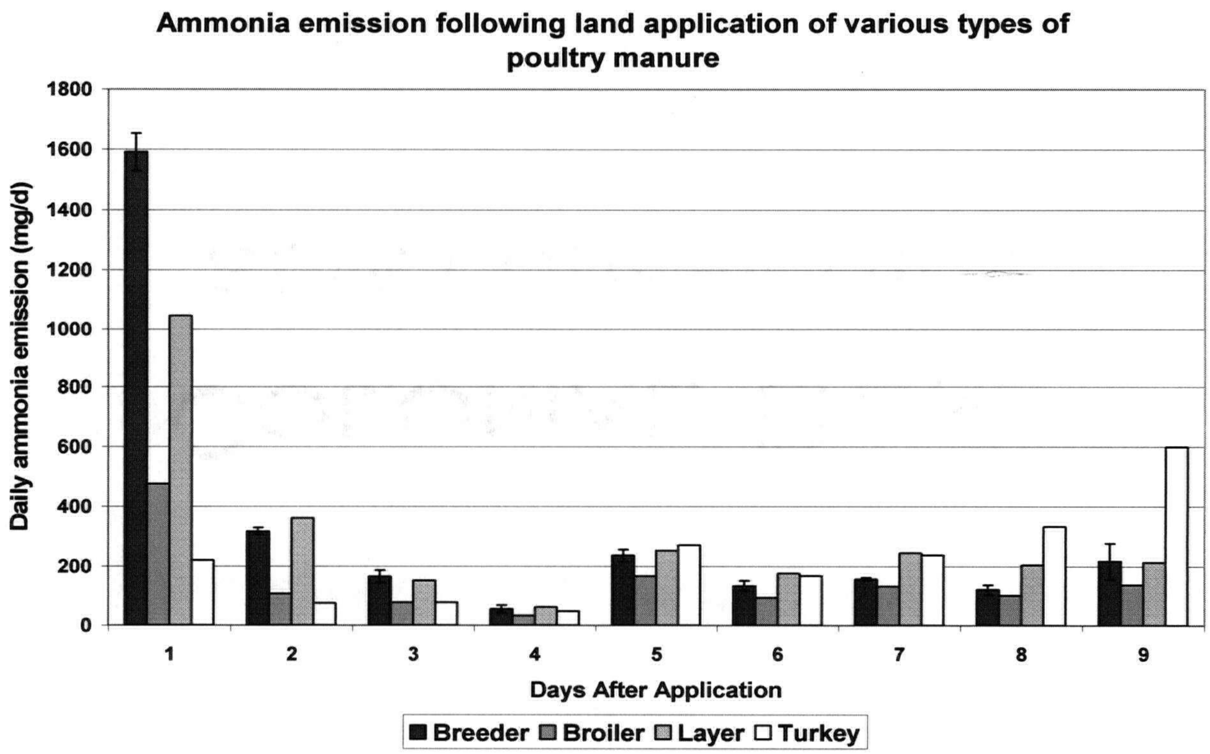

Figure 4.9 Ammonia emission rates for the various types of poultry manure – spring 2006 trial

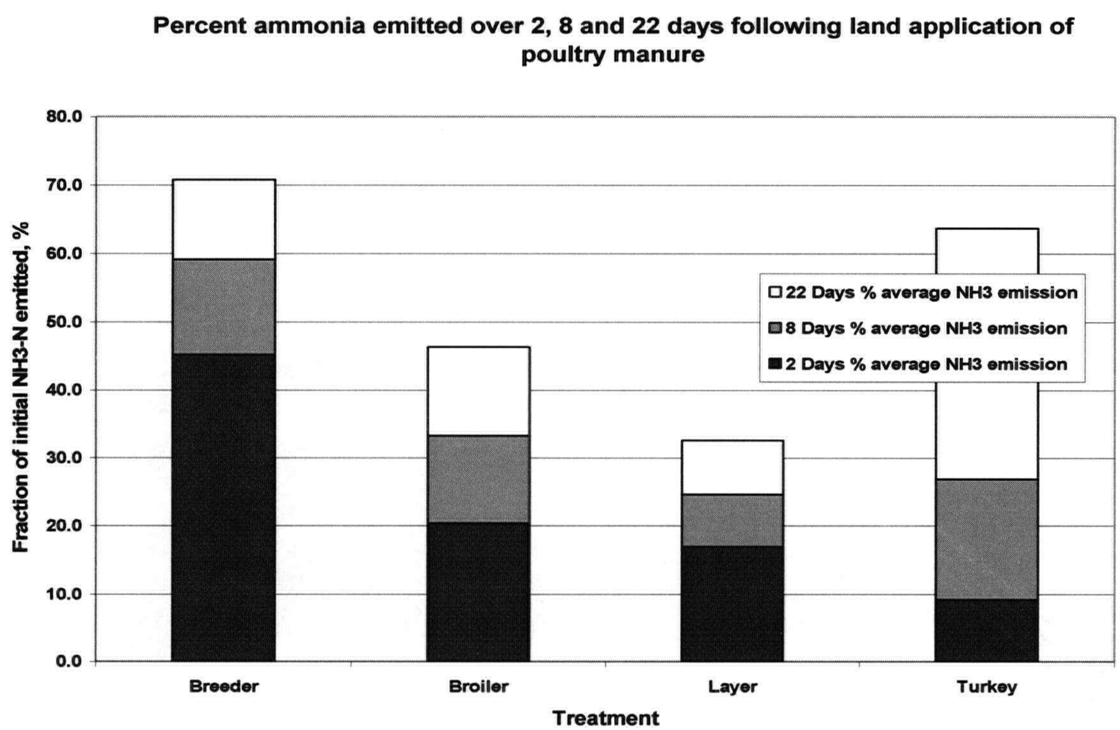

Figure 4.10 Percent ammonia emission – spring 2006 trial

4.5 Effects of Temperature and Humidity

Many factors can affect the NH3 volatilization rate and amount from the soil; air temperature, humidity, and wind speed are positively correlated with NH3 loss. Estimates of the total percent of NH4–N lost during waste storage, or after land application, vary from 10 to 100% of the NH4–N fraction (Mahdi et al., 2002). This wide range in measured NH3 losses results from differences in waste composition, climatic conditions, soils, application methods, and the techniques used for measuring NH3 fluxes. They found that high temperatures and wind speeds increased NH4–N loss during effluent application and from the soil. It was not possible to separate the combined effect of both parameters on NH4–N loss from sprinkler and soil. However, it was evident that higher air temperatures increased NH4–N loss during May and November of 1999, and high wind speeds increased NH4–N loss during 3rd and 6th of May 1999 (Al-Kaisi et. al. 2002). Their results show the percentage of NH4–N loss was affected by both temperature and wind speed changes.

Temperature was consistently higher during the spring 2005 trial versus the fall 2005 trial. The difference in temperatures ranged from 4.7°C to 12.5°C in the first 48 hours after manure spreading, when ammonia emissions were the highest, as illustrated in Figure 4.11. Relative humidity was also observed to be lower (Figure 4.12) for the spring trial (50-100%) versus the fall trial (80-100%). It shall be noted that spring 2006 was also warmer than fall 2005.

Ammonia emissions are expected to be higher in spring and summer times with higher ambient and soil temperatures. Daily ammonia emission rates, as previously displayed, were higher for all types of manure in both spring trials than the fall 2005 trial, and the maximum daily emission rates were seen in the summer trial.

Since the manure application rates were different for the spring and summer 2005 trials versus the fall 2005 and spring 2006 trials, a comparison was made between the trials, based on ammonia emitted as a fraction of the initial amount of ammonium-nitrogen present in manure. Results then indicated that, despite the variations of ammonium-nitrogen out of total nitrogen content in the manure, the fraction of ammonia emitted was consistently greatest in fall 2005 for the breeder, broiler and layer manure. Likewise, the fraction of ammonia emitted from the broiler manure used in the summer trial was also close to that of the fall trial. Turkey manure had the lowest emission in fall 2005, but this may rather be attributed to its pH value lower than 6, which is not favorable for ammonia volatilization.

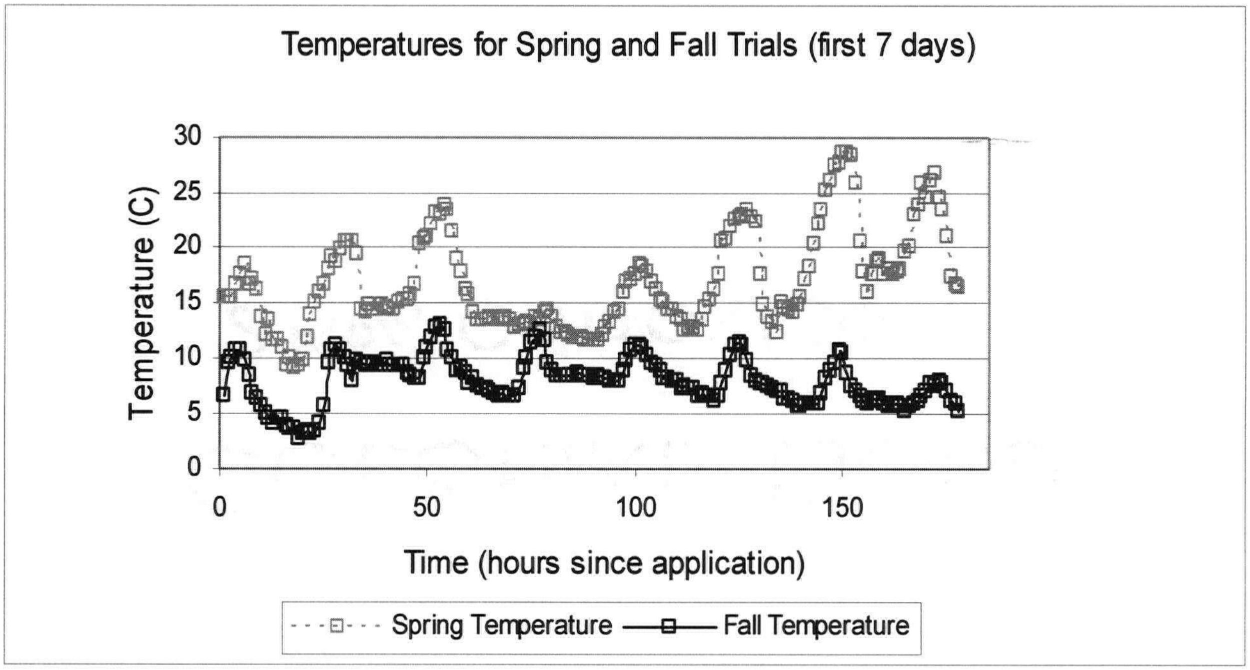

Figure 4.11 Temperature measurements for the spring and fall trials

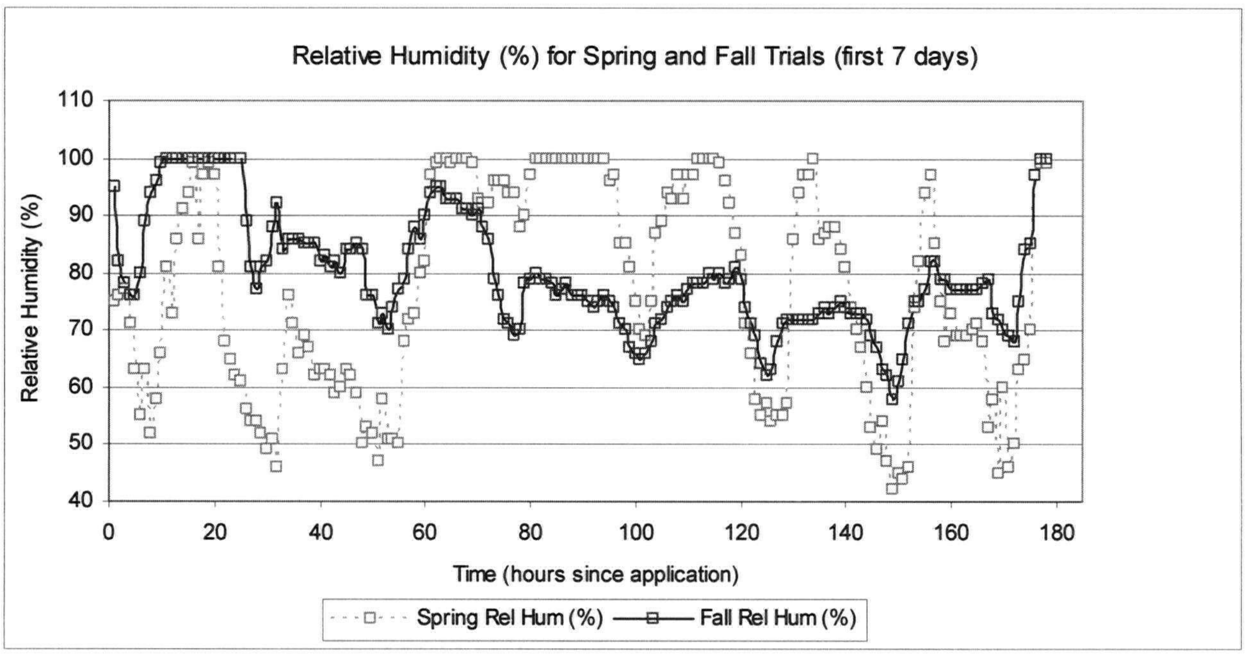

Figure 4.12 Relative humidity measurements for the spring and fall trials

4.6 Ammonia Emission Factors

A summary of the values and seasonal emission factors based on UAN and TN are depicted in Table 4.4 and Table 4.6. The ammonia emission factors derived demonstrate all treatments did not exceed the initial amount of TAN present in manure for all trials and variations with season and among the various types of poultry manure. Overall, the magnitudes of the emission factors based on percent of total nitrogen are comparable to findings from other research studies, for instance, 0.033-0.24 (Huijsmans et. al. 2003) and 0.135 for broiler litter without incorporation (Misselbrook et. al. 2005). Turkey manure had the lowest emission in fall 2005; this may be attributed to its pH value being lower than 6, which is not favorable for ammonia volatilization. Layer manure exhibited the most consistent trend during all trials.

The revised ammonia emission factors as presented in Table 4.5, obtained by taking the average values of the emission factors from all trials, were then obtained on the basis of the average values of the seasonal variations. For comparison, the current values of emission factors adopted by Environment Canada (2005) are also shown in Table 4.5, and emission factors used by other countries are shown in Table 2.1. For the two major types of poultry – broiler and layer, current emission factors of 0.11 and 0.15 are very close to the updated values of 0.12 and 0.16, respectively. A large difference was induced for the turkey manure, with current value and revised value of emission factor being 0.38 and 0.11, respectively. The revised value of 0.11 is similar to broiler manure, as both types of poultry use a lot of bedding materials. It may also be attributed to the high nitrogen content of the turkey manure used in all trials of this project (6.0-7.5% d.b.), as compared to nitrogen contents of 4.0-5.0% d.b. previously reported by the Sustainable Poultry Farming Group (SPFG) (BCMAFF 1997). By comparison, the measured nitrogen contents of other manure types were all similar to the previously reported values - for breeder, (2.9-4.3%) versus (SPFG 2.6-3.6%); for broiler, (2.7-4.7%) versus (SPFG 4.6%) and for layer/pullets, (4.6-6.3%) versus (SPFG 4.1-6.6%). These emission factors are pertinent to "uncontrolled emissions", and are reported as "the amount of NH_3-N volatilized as a percentage of total N in poultry manure".

Preliminary work on uric acid analysis was performed with an aim to delineate whether "ammonia emissions from land spreading of poultry manure can persist for many weeks because of the slow conversion of uric acid to urea, and hence ammonia (Misselbrook et. al. 2000)", or, "most of the uric acid would have been converted to ammonium within a few days of the in-barn storage of the manure (Nahn 2005)". The all manure used in the experiments were acquired from commercial poultry barns, either fresh, in-barn storage, or stored as covered piles outdoor. The ammonia emission measurements and patterns suggested that, regardless of the age of manure, the latter scenario was likely more applicable to the findings from this study.

If the ammonia emission factors are to be expressed relative to uric-acid plus ammonium-nitrogen (UAN) content rather than total nitrogen (TN) content of poultry manure, then the emission factors could become substantially different for the broiler, layer and turkey manure, as evident in Table 4.4. It shall be noted, however, that most of the UAN values were adapted from Nicholson et al. 1996, except for the spring 2006 data. Although emission factors based on UAN might be more representative of poultry manure as an effective nitrogen source, the values estimated here need to be verified with the analysis of uric acid content for many more samples in the future.

The major errors would lie with the ammonia concentration measurements by the flow injection analyzer. The device occasionally produced results from the wrong sample; however, all samples were analyzed repeatedly until the results were consistent. Another error is in the collection of acid traps containing ammonia, where most or all of the acid contents was found to have evaporated from its container. In these cases, other replicates were used to compensate for the loss in data. Therefore, with multiple replicates and repeated analyses, the values are considered fairly accurate, as reflected in the standard deviations of the emission factors shown in Table 4.4 or Table 4.6.

Table 4.4 Ammonia emitted as a fraction of various forms of initial nitrogen

		Spring 2005	Fall 2005	Spring 2006
breeder	kg NH_3 kg^{-1} initial TAN kg NH_3 kg^{-1} initial TN	0.35 ± 0.03 0.09 ± 0.01	0.85 ± 0.05 0.30 ± 0.02	0.71 ± 0.05 0.20 ± 0.01
broiler	kg NH_3 kg^{-1} initial TAN kg NH_3 kg^{-1} initial TN	0.57 ± 0.18 0.12 ± 0.03	0.70 ± 0.07 0.12 ± 0.01	0.46 ± 0.10 0.09 ± 0.02
layer	kg NH_3 kg^{-1} initial TAN kg NH_3 kg^{-1} initial TN	0.37 ± 0.10 0.23 ± 0.06	0.40 ± 0.04 0.06 ± 0.01	0.33 ± 0.06 0.18 ± 0.03
turkey	kg NH_3 kg^{-1} initial TAN kg NH_3 kg^{-1} initial TN	0.25 ± 0.04 0.08 ± 0.02	0.22 ± 0.02 0.10 ± 0.01	0.65 ± 0.09 0.14 ± 0.02

NH_3-N: ammonium-nitrogen; UAN: uric-acid plus ammonium-nitrogen; TN: total nitrogen

Table 4.5 Comparison of current values and revised values of ammonia emission factors*

	Current values kg NH_3/initial kg NH_3	Revised values kg NH_3/initial kg NH_3	Current values kg NH_3/initial kg TN (based on TN)	Revised values kg NH_3/initial kg TN (based on TN)
breeder	0.50	0.64	0.15	0.20
broiler	0.50	0.59	0.11	0.12
layer	0.50	0.37	0.15	0.16
turkey	0.50	0.37	0.38	0.11

* Current values: adopted by Environment Canada (2006); Revised values: derived from this study

Table 4.6 Manure Analysis and Application Rates

Type of manure	Application rate, kg/m^2	Moisture content, % w.b.	Total nitrogen, % d.b.	Ammonia-N, % d.b.	pH	Emission Factor kg NH_3/kg initial TN	Emission Factor kg-NH_3/kg initial-TAN
Spring 2005 Manure Types Trial							
breeder	2.08	33.3	2.98	0.72	8.4	0.09 ± 0.01	0.35 ± 0.03
broiler	2.79	36.7	2.67	0.57	8.5	0.12 ± 0.03	0.57 ± 0.18
layer	1.26	79.5	6.26	3.88	6.5	0.23 ± 0.06	0.37 ± 0.10
turkey	0.74	41.6	7.35	2.33	8.4	0.08 ± 0.02	0.25 ± 0.04
Summer 2005 Grass Heights Trial							
broiler	2.79	36.7	2.67	0.57	8.1	0.14 ± 0.03	0.64 ± 0.13
Fall 2005 Manure Types Trial							
breeder	0.56	23.0	2.89	1.22	8.8	0.30 ± 0.02	0.85 ± 0.05
broiler	0.68	32.1	3.06	0.52	8.9	0.12 ± 0.01	0.70 ± 0.07
layer	0.30	13.4	5.90	0.82	7.9	0.06 ± 0.01	0.40 ± 0.04
turkey	0.30	29.0	7.53	1.84	5.9	0.10 ± 0.01	0.22 ± 0.02
Spring 2006 Manure Types Trial							
breeder	0.52	31.7	4.26	1.20	7.3	0.20 ± 0.01	0.71±0.05
broiler	0.41	22.1	4.73	0.90	7.5	0.09 ± 0.02	0.46±0.10
layer	0.71	53.7	4.55	2.53	7.3	0.18 ± 0.03	0.33±0.06
turkey	0.36	29.6	5.95	1.26	6.7	0.14 ± 0.02	0.65±0.09

w.b.: wet basis

d.b.: dry basis

CHAPTER V – Conclusions and Recommendations

5.1 Conclusions

Based on the field trials performed under contrasting conditions in 2005 and 2006, total ammonia emissions based on TN and TAN were significantly different between manure types ($p < 0.005$), but the ranking varied with trial. Other than the turkey manure used in spring 2006, the highest emission rate occurred immediately proceeding application, then gradually declining in the 2-3 weeks period towards the end of the trial. By cultivating the manure within 24 h, emission reduction of over 50% can be achieved, but a delay of 48 hrs would usually lead to a reduction of only 35-40%. As expected, ammonia emission rates were generally greater in both of the spring trials compared to the fall trial.

In spite of the differences of TAN content versus TN content in the four types of manure, ammonia emitted as a fraction of the initial amount of TAN present in manure was consistently greatest in fall 2005 for the breeder, broiler and layer manure. However, turkey manure had the lowest emission in fall 2005; this may be the result of its pH value being lower than 6, which is not favorable for ammonia volatilization. Within the monitored period, the initial amount of NH_3-N in the manure for all treatments was never exceeded by the cumulative ammonia emission, suggesting that the conversion of uric acid to ammonia after land application might not be significant for the manures used in these trials.

Based on the spring and fall trials, ammonia emissions were significantly different between the manure types ($p < 0.005$). For the summer trial, ammonia emitted as a percent of initial NH_3-N was 50% for the high grass height of 275 mm, as compared to 65-70% for the other grass canopies (25-175 mm). However, the differences in emission rates were not statistically significant ($p > 0.1$).

The summer trial examining the effects of grass height on emissions revealed that ammonia-nitrogen uptake increased with grass height; however, wind speed was also identified to be the major factor, as a taller grass canopy led to less turbulence in the boundary layer, reducing ammonia diffusion and further ammonia volatilization from the soil surface. Statistically, there was no significant difference ($p > 0.10$) in ammonia volatilization between treatments of 25mm, 75mm, 175mm and 275mm of orchard grass.

The quantity of ammonia emitted within 24 hours (day 1), expressed as a percentage of the total ammonia emission over the duration of each trial, was found to be 48%, 41%, 38% and 29% for breeder, broiler, layer and turkey manure, respectively. Moreover, most of the emission in the first day took place within the first 2-5 hours after land application of manure. By day 7, the cumulative total ammonia losses reached 83%, 81%, 80% and 67% for these four types of manure. This information would prove useful in guiding the timing and abatement value of incorporating manure after spreading.

The ammonia emission factors derived from the experimental results of this study demonstrate variations among the various types of poultry manure. For the two major types of poultry – broiler and layer, current emission factors of 0.11 and 0.15 adopted by Environment Canada are very close to the updated values of 0.12 and 0.16, respectively. However, substantial difference was induced for the turkey manure, with current value and revised value of emission factor being 0.38 and 0.11, respectively. The revised value of 0.11 is similar to broiler manure, as both types of poultry use a lot of bedding materials. It may also be attributed to the high nitrogen content of the turkey manure used in all trials of this project.

The EC guidelines for reporting ammonia emission factors are taken from the Criteria Air Contaminants guidebook, an unpublished document (Environment Canada, 2006). Upon analyzing the data and information from, the following assumptions were realized:

a) The NH3:TN ratio is 0.62, which means, ammonium-nitrogen constitutes 62% of total nitrogen in excreted turkey manure.

b) 50% of the available nitrogen (as NH3-N) initially present in manure is volatilized after land application of manure

These assumptions are not applicable to the results obtained in the present study. Firstly, manure analysis indicates that the NH3:TN ratio for turkey manure is 0.21-0.32 (Table 3.1), which is substantially lower than 0.62. Secondly, the amount of NH3-N volatilized is 37% of the NH3-N initially present in turkey manure (Table 4.5), rather than the assumed value of 50%. This is the reason for the discrepancies between the two values, 0.38 versus 0.11, when ammonia emission is expressed in [kg NH3/initial kg TN] or [%TN].

It is also realized that the Environment Canada values of the emission factors are numerically the same in units of [kg-NH3/initial kg-N] or [kg NH3/animal/year]. Environment Canada could have adopted these values with reference to European data (Table 2.1) (Kuczynski et al 2005). Furthermore, it would suggest that the manure nitrogen excretion rate was assumed by EC to be [1.0 kg N/bird/year], as the conversion factor between the two units. This assumed conversion factor is compatible with those reported in the literature for turkey manure, being [1.1 kg N/bird/year] (USEPA, 2005) and [0.9 kg N/bird/year] (Ohio State University, 2007), for 6 cycles of production per year and 37 days per cycle, typical in the BC poultry industry. Nevertheless, this assumed value is substantially different for layer and broiler manure, since values of 0.22-0.29 kg N/bird/year and 0.12-0.25 kg N/bird/year are given by USEPA (2005) and OSU (2007).

As mentioned earlier, poultry manure may be applied to vegetable crops, grass and cereals in BC. However, this study was done in parallel with a project (at Agassiz Research Station) that concerns the land application of dairy manure, which is largely for grass. From the observations and conclusions of this study, ammonia volatilization was greater with breeder and broiler manure. If possible, it is therefore more efficient to utilize the nutrients in layer and turkey manure as fertilizer. Using additives in the manure to reduce the pH would reduce ammonia emissions, which means, more nitrogen would be available for plant growth. Farmers can follow the application guidelines similar to those used in this study. However, the manure pH will vary from farm to farm. When making recommendations to Environment Canada on the effects of the various factors, the effect of pH will be singled out as the dominant factor, as it seems to override the effects of temperature. Since pH was found to be the dominant factor, it is possible to predict whether ammonia emission may be higher or lower based on the pH value of manure. However, further trials may be required to obtain more data points in order to develop a regression equation with high R2 value. A lower wind velocity would also reduce ammonia volatilization; hence, measures taken to limit wind speeds at the soil-manure surface could also contribute to reduced nutrient losses.

5.2 Recommendations

Poultry manure samples collected from farms for this study did not always possess characteristics similar to manure found most common in the area; more specifically, the moisture content and total nitrogen of the manure may vary between barns utilizing different equipment and operations. However, it was difficult to find farmers with available manure; either manure inside the barn had yet to be transferred to a storage facility, or the manure had been removed from storage to disposal or application. For consistency, all manures should be collected either during the housing or storage stage from poultry farms representative of those most commonly found in the Lower Fraser Valley.

The air velocity inside the wind tunnel is generally higher than regular wind speeds; however, the blower was already set at the minimum setting. A device that could simulate lower wind speed would likely yield ammonia emission factors most representative of British Columbia. Inside Tygon tubes, condensation will remove ammonia from the air sample being drawn into the acid trap. Whenever moisture was observed inside a tube, it was immediately replaced by a dry duplicate. Ideally, the tubes should be free of moisture at all times during experimentation.

Evaporation during hot summer days occasionally caused the acid traps to run dry; larger volume of acid, ventilation of the container in which the acid trap sits, or frequent shift changes of the sample would eliminate the chance of losing data. The flow injection analyzer often had difficulty at reading the concentration of ammonia in the sample. A more consistent method of analysis can potentially reduce the error margins.

It was found that manure pH is a dominate factor in estimating ammonia volatilization. In future studies where the main objective is to limit emissions of ammonia from poultry manure, additives of acid or base should be used to manipulate manure pH as a primary variable in the experiments. In comparison with this study, the manure types and grass heights would be kept constant, as well as all other controlled variables.

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APPENDICES

Appendix A – Sample Calculations

Ammonia emission of a shift

Equation 1

$$E = (C_o - C_i)\ V\ R$$

Where:

E	ammonia emission rate based on sub-sample tunnel air, [mg per interval]
C_o	concentration of ammonia at blower intake [mg/L]
C_i	concentration of ammonia at tunnel intake [mg/L]
V	volume of acid trap solution [L]
R	ratio of actual airflow rate to the sub-sample airflow rate = v A/Q
v	rotary anemometer speed anemometer wind speed [m/s]
A	tunnel cross sectional area [m^2]
Q	sub-sample flow rate [m^3/hr]

From spring 05 first replicate of turkey manure, shift one on day one.

Given: C_o = 1.861 mg/L NH_3-N, C_i = 0.351 mg/L, V = 0.029575 L

Q = 0.1494 m^3/h, A = 0.01675 m^2, v = 13.5 m/s

R = (13.5 m/s)(0.01675 m^2)(3600 s/h)/(0.1494 m^3/h)

R = 5449.6

E = (1.861 mg/L – 0.351 mg/L)(0.029575 L)(5449.6)

E = 1035.8 mg per interval

Ammonia emission factor

From spring 05 of turkey manure, all shifts over the trial period for all replicates.

Given: The duration of the spring 05 trial is 16 days

The mass of ammonia emitted for the 4 replicates are 2903.4, 2421.0, 2129.2, 2743.5 mg.

From Table 3.1, the application rate, moisture content, percent total nitrogen (dry basis) and percent ammonia (dry basis) are 0.74 kg/m^2, 41.6%, 7.35%, 2.33%, respectively.

Total nitrogen in the manure applied $= (0.74\ kg/m^2)(1\text{-}0.416)(0.0735)(0.5m*2.0m)$
$= 0.318$ kg or 31,800 mg

Average of total ammonia emitted of turkey manure $= (2903.4 + 2421.0 + 2129.2 + 2743.5)(4)^{-1}$
$= 2549.3$ mg

Emission Factor for turkey in spring 05 in kg-NH3-N/kg-initial-N $= (2549.3\ mg)(31,800\ mg)^{-1}$
$= 0.080\ kg\ NH_3\ kg^{-1}$ initial TN

Total ammonia in the manure applied $= (0.74\ kg/m^2)(1\text{-}0.416)(0.0233)(0.5m*2.0m)$
$= 0.100$ kg or 10,000 mg

Emission Factor for turkey in spring 05 in kg-NH3-N/kg-initial-N $= (2549.3\ mg)(31,800\ mg)^{-1}$
$= 0.25\ kg\ NH_3\ kg^{-1}$ initial TAN

A table containing spring 05 emission data in mg for each shift and day for all treatments and replicates are shown below, where treatment 1 through 4 are turkey, broiler, breeder, and layer, respectively; treatment and replicate numbers are abbreviated to T and R (T1R2 referring to replicate 2 of treatment one, for example).

A second table contains the total ammonia emission of each shift and day average between all replicates of each treatment and the sum of shifts taken within each day.

The third table contains the daily ammonia emission derived from the sum of shifts from each day or days.

Ammonia emission from each shift – spring 2005

	Day 1			2		3		4		5		7		8		9		10		12			16		
	Shift 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	25	16 days [mg] Me16	2 days [mg] Me2
T1R1	1035.760	162.238	308.136	227.442	364.714	120.434	75.920	68.582	21.998	5.928	56.740	120.298	91.570	48.079	49.998	14.040	11.990	0.000	57.805	25.774	31.578	2.466	1.903	2903.394	2757.838
T2R1	1495.189	412.785	836.877	578.645	596.887	208.698	136.489	123.155	31.541	54.459	194.491	245.168	159.390	76.324	88.870	24.815	13.310	18.203	148.026	78.419	67.409	45.404	13.830	5648.387	5238.969
T3R1	994.778	186.932	383.424	221.064	326.156	144.909	100.394	90.199	27.548	47.325	125.708	199.422	153.447	69.880	57.727	40.031	73.588	36.965	144.598	69.039	50.146	33.468	39.023	3615.774	3128.914
T4R1	267.820	99.230	523.259	494.907	316.735	262.947	119.529	133.934	64.624	68.484	104.566	63.842	42.772	12.591	20.518	28.754	21.268	20.404	37.653	37.432	7.402	33.419	65.572	2847.662	2595.758
T3R2	872.963	253.027	498.906	285.350	402.048	124.808	82.555	66.261	51.510	50.336	146.701	227.847	154.129	62.894	60.917	34.767	45.845	51.056	162.599	77.842	75.908	47.015	50.763	3886.048	3340.252
T4R2	347.991	209.166	579.481	570.416	598.001	316.812	146.023	150.488	38.532	59.163	125.098	134.950	25.963	32.730	12.662	24.875	14.015	13.286	32.385	17.071	31.263	15.648	48.762	3544.782	3347.476
T1R2	567.777	190.586	373.798	170.163	350.928	102.153	50.306	48.871	5.699	18.249	51.769	111.020	79.036	42.568	41.313	18.335	13.826	38.837	62.517	32.106	34.099	7.134	9.920	2421.011	2204.236
T2R2	1071.126	415.415	598.775	459.688	489.142	185.726	144.645	79.624	49.522	50.151	127.333	221.656	145.600	70.188	61.537	24.166	28.180	26.683	120.814	48.271	72.005	27.884	41.045	4559.175	4170.125
T4R3	141.804	203.109	296.070	468.490	600.557	404.709	245.900	183.460	60.755	79.053	158.724	157.263	70.986	18.208	64.122	24.085	42.498	8.482	45.324	14.084	14.266	31.942	44.825	3378.715	3153.211
T1R3	279.842	250.061	303.557	180.567	327.907	129.919	81.038	60.895	15.528	12.291	48.331	91.501	84.396	60.800	17.689	20.169	11.925	13.058	50.020	35.898	27.617	26.238	0.000	2129.248	1944.323
T2R3	1839.595	812.953	748.513	933.876	800.874	341.734	144.051	181.463	67.052	48.818	338.895	486.071	294.568	139.969	67.005	51.457	55.881	83.424	310.332	126.603	188.190	71.149	83.126	8215.599	7245.437
T3R3	633.012	311.719	330.240	291.556	316.087	156.076	128.402	83.031	45.904	63.636	289.036	170.349	114.473	54.801	47.442	25.166	57.679	40.949	95.036	47.251	31.724	68.886	51.643	3454.097	3035.763
T2R4	1060.442	471.548	486.023	423.651	507.111	203.980	163.915	102.541	17.891	10.109	103.926	239.033	127.782	67.853	40.533	14.556	13.191	7.016	50.818	27.598	3.429	5.972	64.673	4213.591	4026.339
T4R4	242.860	231.613	396.744	585.719	586.904	436.976	216.520	218.763	91.608	85.981	153.934	99.980	77.423	39.536	28.362	36.335	57.156	196.465	331.979	151.597	277.081	158.170	384.567	5086.275	3492.923
T3R4	576.517	262.904	316.384	240.297	261.701	176.286	119.159	62.914	33.843	39.404	125.611	202.792	0.000	65.133	51.415	77.383	65.326	47.394	143.664	90.030	106.489	52.721	23.223	3140.589	2534.358
T1R4	818.361	256.082	259.794	173.217	341.147	116.604	83.388	66.384	12.598	19.063	63.277	129.630	42.085	111.816	44.080	34.373	11.810	18.410	67.838	31.909	17.448	2.641	21.506	2743.461	2537.526

Average ammonia emission from each shift – spring 2005

	Day 1			2		3		4		5		7		8		9		10		12			16
	Shift 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	25
TKY	675.44	214.74	311.32	187.85	346.17	117.28	72.66	61.18	13.96	13.88	55.03	113.11	74.27	65.82	38.27	21.73	12.39	17.58	59.55	31.42	27.69	9.62	8.33
BROIL	1366.59	528.18	667.55	598.96	598.50	235.03	147.28	121.70	41.50	40.88	191.16	297.98	181.84	88.58	64.49	28.75	27.64	33.83	157.50	70.22	82.76	37.60	50.67
BREED	769.32	253.65	382.24	259.57	326.50	150.52	107.63	75.60	39.70	50.18	171.76	200.10	105.51	63.18	54.38	44.34	60.61	44.09	136.47	71.04	66.07	50.52	41.16
LYR	250.12	185.78	448.89	529.88	525.55	355.36	181.99	171.66	63.88	73.17	135.58	114.01	54.29	25.77	31.42	28.51	33.73	59.66	111.84	55.05	82.50	59.79	135.93

Appendix B – Procedure of Analyses

Uric Acid Analysis

1. The poultry manure samples are first weighed then freeze dried for one week to minimize degradation. The sample is weighed again to measure the moisture/dry matter content.
2. Freeze dried samples are ground to lower particle size for better liquid-solid extraction.
3. Uric acid was extracted using 1M $NaCO_3$ over 24 hours.
4. The solution was centrifuged and 50 ml of the supernatant was obtained for analysis.
5. Reagents from the Bioassay Systems' uric acid assay kit are prepared prior to analysis using a spectrophotometer.
6. The sample is combined with the reagents at the appropriate amount and incubated for 20 to 60 minutes at room temperature.
7. The blank, standard, and samples were transferred to 3 ml cuvettes and the optical density was read at 590 nm.
8. The uric acid concentration of the sample was calculated by the following equation:

$$(10 \text{ mg/dL})(OD_{sample} - OD_{blank})/(OD_{standard} - OD_{blank})$$

where:

OD_{sample} Optical density of the sample;

OD_{blank} Optical density of the blank; and

$OD_{standard}$ Optical density of the standard.

Given: $OD_{sample} = 0.490$, $OD_{blank} = 0$, $OD_{standard} = 0.714$

UA Concentration = (10 mg/dL)(0.490 – 0)/(0.714 – 0)

UA Concentration = 6.86 mg/dL

9. The mass of uric acid content in each sample is found by multiplying the dry matter content with the uric acid concentration.

Flow Injection Analyzer (FIA) Analysis

1. Reagents for analyzing ammonia are prepared following the manual provided by the manufacturer. Once prepared, Teflon tube lines, each labelled with the name of the reagent it is meant for, are placed into the appropriate containers to condition the lines using a displacement pump.
2. Prepared samples obtained from acid traps are poured into test tubes custom to the FIA. Up to 60 samples can be measured every set.
3. The temperature of the FIA is set to 60°C, appropriate for NH_3 analyses.
4. On the computer from which the FIA is controlled, each test tube was labelled according to the shift and tunnel from which the sample originated.
5. Standards and samples are placed into the rack from which sub-samples are drawn.
6. The analyzer then reads the ammonia concentration [mg/L] based on the calibration curve obtained from reading the standards.

Manure pH Analysis

1. A sample of manure was weighed to an arbitrary value of 1 gram; the sample was then transferred into a 50 ml test tube.
2. Water was added into the test tube to fill to a volume of 10 ml.
3. The test tube was covered/capped and shaken for 1 minute; the pH of the solution was measured and recorded.
4. Water was again added to volumes of 15, 20, and 25 ml; the sample was again shaken and the pH measured and recorded.
5. A volume of sample versus pH curve was plotted, the linear fit for the 4 data points extrapolated to a water volume of 0 was determined as the manure pH.
6. The average of 3 manure pH values determined by this method was used as the actual manure pH.