Development of ammonia emission factors for the land application of poultry manure in the Lower Fraser Valley of British Columbia

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Lau, A. K., Bittman, S. and Hunt, D. E. 2008. Development of ammonia emission factors for the land application of poultry manure in the Lower Fraser Valley of British Columbia. Canadian Biosystems Engineering/Le génie des biosystèmes au Canada 50: 6.47–6.55. The objective of this study was to monitor ammonia emissions and develop updated ammonia emission factors for land application of poultry manure under British Columbia conditions. Field trials, which involved four types of poultry manure as the fertilizer materials, were performed at Agassiz Research Station in 2005 and 2006. After manure application, ammonia emission rates were determined using wind tunnels, capturing the emitted ammonia with acid traps and analyzing 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 proposed revised ammonia emission factors of 0.12 and 0.16 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 vs. 0.13) were substantially different for turkey manure. **Keywords:** poultry manure, manure application, ammonia emission, emission factor, total nitrogen, ammoniacal-nitrogen, wind tunnels, acid traps.

L'objectif de cette étude était de mesurer les émissions d'ammoniaque lors de l'épandage de fumier de volailles sous des conditions typiques de celles rencontrées en Colombie Britanique et de déterminer des facteurs d'émission appropriés. Des essais aux champs ont été réalisés à la station de recherche Agassiz en 2005 et 2006 en utilisant quatre types de fumier de volailles utilisés comme fertilisant. Les taux d'émissions d'ammoniaque ont été mesurés suite aux opérations d'épandage en utilisant des tunnels de ventilation et en capturant l'ammoniaque émis à l'aide de trappes à acide et en faisant l'analyse avec un analyseur à débit d'injection. Pour tous les essais, les plus hauts taux d'émissions ont été observés durant la première journée suivant l'épandage du fumier et ont par la suite graduellement diminué au cours des deux ou trois semaines qui ont suivi. Les émissions d'ammoniaque cumulatives pour tous les traitements n'ont pas excédé les quantités initiales d'azote ammoniacal présentes dans le fumier. Les taux d'émissions d'ammoniaque étaient significativement différents pour différents types de fumier ($p < 0,005$). Le pourcentage total de perte d'ammoniaque dans le temps présentait une corrélation positive avec le pH du fumier. Les taux d'émissions d'ammoniaque étaient généralement plus élevés dans les deux essais printaniers que dans l'essai automnal. Les facteurs révisés d'émissions d'ammoniaque qui sont proposés sont : 0,12 et 0,16 respectivement pour les deux types de fumier volailles les plus courants (poulets à griller et pondeuses) et ces valeurs sont comparables avec celles des facteurs d'émissions courants adoptés par Environnement Canada. Dans le cas du fumier de dinde cependant, les facteurs d'émissions courants et révisés (0,38 versus 0,13) étaient très différents. **Motsclés:** fumier de volailles, épandage, émission d'ammoniac, facteur d'émission, azote total, azote ammoniacal, tunnels de ventilation, trappe à acide.

INTRODUCTION

Ammonia emission, which originates primarily from agricultural sources, has been identified as one of the quantitative indicators of agricultural environmental performance in Canada (Lefebvre et al. 2005). The Canadian emission inventory (Environment Canada 2006) indicates that livestock production was the dominant source of ammonia emission (54% of total emissions) followed by application of mineral N-fertilizers (34% of total emissions) in 2002. In livestock production systems, ammonia loss occurs from animal housing, storage and manure spreading (Nicholson et al. 2004). Based on current estimates, about 6% of all Canadian emissions can be attributed to land application of poultry manure. Poultry production in British Columbia (BC) constitutes some 15% of the total production in Canada, most of it concentrated in the Lower Fraser Valley, generating approximately 300,000 tonnes of manure each year. The Lower Fraser Valley in BC has intensive livestock production. Losses of ammonia are important to quantify in order to predict local deposition, nitrogen balances and impact on air quality, especially the formation of secondary fine particulate matter less than 2.5 μm, which is often composed of ammonium nitrate and ammonium sulfate. The smog thus formed accounts for 75% of the visibility impairment in the region and may be contributing to health problems.

The objective of this study was to investigate ammonia emissions from the application of manure from the various types of poultry operations in spring and autumn, that is, timings when these applications are likely to occur. These data will be used to update ammonia emission factors for BC and Canada.

BACKGROUND RESEARCH

Ammonia emission factors

Ammonia emission factors are available for total emissions of various livestock classes from the combined activities of housing, storage and land application, for instance, in Austria, Czech Republic, Finland, Russia and USA (Kuczynski et al. 2005). However, data specifically for land application of poultry manure are very limited.

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 (including roasters and Cornish), turkeys and other poultry (including ducks and geese). Magnitudes of ''uncontrolled emission factors'' are based on the assumption that 50% of initial available N is volatilized as ammonia-N (NH_3-N), and reported as the amount of ammonia (NH_3) volatilized as% TN (total nitrogen).

''Controlled emission'' refers to emission associated with confinement facilities, and such emission factors are expressed in units of [kg NH_3/animal/year]. USEPA (United States Environmental Protection Agency) adopted a single average value of 0.24 kg NH_3/animal/year for all types of poultry. For ''uncontrolled emission'', USEPA (2005) suggested the amount of NH_3 volatilized as 42% of TN for wet layer manure versus 7% of TN for dry layer manure, whereas turkey manure was assumed to have the same value as broiler manure, at 25% of TN. By comparison, data from Norway encompassed a range of 4% (spring) to 10% of TN (autumn) for dry poultry manure. Emission factors expressed in terms of percent TN for dry manure are in line with the guidelines provided by EMEP/CORINAIR (2002).

Field trials for land application of poultry manure

Ammonia is usually present in air in trace concentrations due to its highly reactive nature. While various methods of measuring ammonia volatilization have been studied by researchers, both the wind tunnel method and the mass flux measurements method were found to be effective. Factors that play an important role in determining ammonia emissions after spreading of manure include: meteorological conditions such as temperature, humidity, turbulence, precipitation; soil properties such as pH, calcium content, cation exchange capacity, water content, infiltration rate and vegetation cover; and manure properties such as pH, viscosity, dry matter content, and method and rate of application (Huijsmans et al. 2003).

A spreading experiment was conducted at Ultuna, Sweden (Rodhe and Karlsson 2002) using broiler manure that had been stored as an uncovered heap for 7 months. The manure was broadcast on arable land with and without harrowing 4 h after spreading at a rate of 110 kg total N ha^{-1} (4.4 t broiler manure ha^{-1}). Ammonia emissions were measured, over a period of 2 and 5 days, respectively. In total, 13.5% of TN in the broiler manure was lost as ammonia after spreading without incorporation of the manure; however, no ammonia emission occurred after incorporation.

A multiyear study quantified NH_3 volatilization rates from broiler litter broadcast under no-till and conservation tillage managements on soil with 100-150 mm tall stubble (Sharpe et al. 2004). Litter was applied to supply 90 to 140 kg N ha^{-1}. Poultry litter was applied after planting and before seed germination. Micrometeorological data and atmospheric NH_3 concentrations were determined for 7-8 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 TN applied with the largest losses under summer (hot, dry, windy) conditions. Losses of 22 to 24% were deemed 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. Precipitation of 17 mm within 48 h of application greatly inhibited volatilization, probably by transporting litter N into the soil matrix, It was concluded that application of poultry litter to conservation-tilled cropland immediately before rainfall events would reduce N losses to the atmosphere but could also increase nitrate (NO_3) leaching and runoff to streams and rivers. Sommer and Olesen (2000) also suggested that rainfall after slurry application would increase infiltration of slurry and TAN (total ammoniacal nitrogen) into the soil and hence reduce TAN concentration in the soil surface. This would reduce ammonia volatilization, although the reduction may be temporary if high temperatures increase evaporation after the rainfall event.

In the United Kingdom, no differences in emissions were found following land spreading of broiler and layer litter, with total ammonia losses averaging 63% (46-92%) of the applied uric acid and ammoniacal N over the 28-day measurement periods (Nicholson et al. 2004). In their project, the target application rate was 250 kg N ha^{-1}, while actual rates varied from 120 to 470 kg N ha^{-1}. Misselbrook et al. (2000) also used an emission factor of 63% with no differences in emissions following land spreading between the various layer manure handling/removal methods or between layer manures from the different commercial unit houses. Total ammonia losses were equivalent to 67–118% of the uric acid and ammoniacal N applied over the same period; losses that exceed 100% might be due to mineralization of organic-N. The authors indicate that slow conversion of uric acid to urea lengthens the ammonia emission period.

Another series of experiments was conducted using wind tunnels to assess the influence of a range of environmental, manure and management variables on ammonia emissions following application of solid poultry and other manures (cattle, pig) to grassland and arable land (Misselbrook et al. 2005). Measurements of NH_3 emission continued for 12 d following manure applications. Differences in temperature were achieved by applying manure at different times of year. The measured TN, TAN and UN (uric acid nitrogen) contents for poultry manure (broiler litter and layer manure) were 1.03–3.3%, 0.35–1.34% and 0.01–0.45%, respectively. For solid manures, rainfall was identified as the parameter with most influence on ammonia emissions, among the variables studied. Linear relationships were established between total NH_3 loss and temperature for the measurements with increases in losses of 3.6 and 4.0% of applied TAN per 1°C increase in temperature for broiler litter and layer manure, respectively. Positive correlation between temperature and NH_3 loss has also been confirmed by Dewes (1996) and Balsari et al. (2008) in their studies involving livestock manure. Wulf et al. (2002) attributed their observations of a diurnal rhythm of emission (higher during the day and lower at night) to temperature effects on NH_3 solubility and the equilibrium concentration of NH_3 and NH_4^+ according to Henry's law.

Søgaard et al. (2002) showed that the total ammonia volatilization increased with increasing cattle and pig slurry DM (dry matter) content and TAN content. According to Sommer and Olesen (2000), both TAN and slurry pH are important factors when modelling volatilization after application. For the application of pig or cattle slurry to cereals, the researchers reported an increase in the concentration of dissolved NH_3 and thereby the NH_3 volatilization with an increase in soil slurry pH. Increase in pH is known to cause a shift in the NH_4^+/NH_3 equilibrium, which may contribute to increased NH_3 volatilization losses (Paul and Beauchamp 1989).

MATERIALS and METHODS

Three field trials were performed in the late spring of 2005, the fall 2005 and in the spring of 2006 at the Pacific Agri-Food Research Centre of Agriculture and Agri-Food Canada at Agassiz, BC. The soils at the experimental sites are silty to sandy loam with about 6% organic matter, and these trials were conducted on orchardgrass (50 mm height). At this location, the mean daily temperature is 13.3°C in May and 10.8°C in October, whereas mean precipitation (rainfall) amounts to 102.5 and 171.8 mm, respectively.

Manure (breeder, broiler, layer, and turkey) was collected from commercial poultry farms in the Lower Fraser Valley of BC Only the broiler and turkey manures contained bedding material (wood shavings). Fresh breeder and broiler manures were used for all trials. Layer manure was recently removed from the barn for the spring trials in 2005 and 2006, but the manure for the fall 2005 trial had been stored in a static pile for several months in a covered shed. Fresh turkey manure was used for the spring 2006 trial, but the litter used in the 2005 trials was stored for several months in a covered static heap. Before application, manure samples were analyzed for pH, moisture, and concentrations of TAN, and TN. Uric acid nitrogen was not determined for this trial as such analysis is not typically available to farmers in Canada. The measured values and the manure application rates are presented in Table 1. The stored layer manure had significantly lower TAN for the fall 2005 trial (0.82%) than that of the fresh and wet manure used in the spring 2005 trial (3.88%). For the spring 2006 trial, both the moisture content and TAN content of layer manure were greater than those of the other three types of manure.

A randomized complete block design was used for the experiment, with four treatments for the various types of poultry manure and four replicates for each treatment. Manure was manually broadcast to the soil surface of 0.5×2 m plots. In the spring 2005 trial, the quantity of manure applied was based on 100 or 470 kg TN ha^{-1}.

Table 1. Manure analysis and application rates

Type of manure	Application rate (kg ha^{-1})	Moisture content (% w.b.)*	Total nitrogen TN (% d.b.)*	Ammoniacal-N TAN (% d.b.)*	pH
Spring 2005 Trial					
Breeder	20800	33.3	2.98	0.72	8.4
Broiler	27900	36.7	2.67	0.57	8.5
Layer	12600	79.5	6.26	3.88	6.5
Turkey	7400	41.6	7.35	2.33	8.4
Fall 2005 Trial					
Breeder	5600	23.0	2.89	1.22	8.8
Broiler	6800	32.1	3.06	0.52	8.9
Layer	3000	13.4	5.90	0.82	7.9
Turkey	3000	29.0	7.53	1.84	5.9
Spring 2006 Trial					
Breeder	5200	31.7	4.26	1.20	7.3
Broiler	4100	22.1	4.73	0.90	7.5
Layer	7100	53.7	4.55	2.53	7.3
Turkey	3600	29.6	5.95	1.26	6.7

*w.b., wet basis; d.b., dry basis.

In the fall 2005 and spring 2006 trials, the application rate was 150 kg TN ha^{-1}. By comparison, broiler manure was applied to arable land at a rate of 110 kg TN ha^{-1} in a field test conducted by Rodhe and Karlsson (2002), and 90 to 140 kg TN ha^{-1} in the multi-season study conducted by Sharpe et al. (2004).

There are guidelines on the poultry manure application rates for different vegetable crops, grass and cereals (BCMAFF 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 orchardgrass. It depends on the moisture content and nitrogen content of manure; greater application rates are required if manure moisture content is higher and nitrogen content is lower.

After manure application, a wind tunnel (Lockyer 1984) was installed for each plot so that the polycarbonate canopy (450 mm high and 500 mm wide) completely covered the application area. The wind tunnels remained in situ for the entire measurement period and therefore were not influenced by rainfall. Air was drawn over the treated area through the tunnel at 1 m s^{-1} with a blower, and air flow rate was continuously monitored with a rotary anemometer placed inside the blower unit of each tunnel. A sub-sample of air was drawn (2–3 L min^{-1}) from an inlet located in front of the blower, through Teflon coated Tygon tubes. The sample air was bubbled through acid traps containing 100 mL of 0.01 M phosphoric acid to capture ammonia. Sulfuric acid solution was used to trap NH_3 by other researchers such as Guiziou and Béline (2005). Prior to passing through the acid trap, the air stream was passed through an empty Erlenmeyer flask to capture dirt. Flow restrictors were used to control the flow rate. The volume of sample air was measured with pre-calibrated cumulative flow meters. Sample air was also collected at the tunnel intake to account for background ammonia.

On the first day when the rate of NH_3 volatilization was anticipated to be highest, the acid traps were changed 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, then once daily over a total measurement period of 2–3 weeks after manure application.

Liquid samples from each shift were stored at 5°C then topped to a standard 120 mL prior to analysis. Samples were analyzed for NH_4 with a flow injection analyzer (Lachat instrument, Model QuickChem 2000). The ammonia emission rate from the entire plot was calculated using the NH_4-N analysis of the acid and the ratio of tunnel airflow rate to the sub-sample airflow rate:

$$E = (Co - Ci)\ V\ R$$

where, E is ammonia emission rate (mg per interval); C_o is concentration of ammonia at blower intake (mg/L); C_i is concentration of ammonia at tunnel intake (mg/L); V is volume of acid trap solution (L); R is the ratio of tunnel airflow rate to the sample airflow rate. The ratio of flow rates was calculated as $v\ A/Q$; v is rotary anemometer wind speed (m/s); and A is tunnel cross sectional area (m^2) and Q is the sample flow rate (m^3/s).

Statistical analysis of the ammonia emission results over various time periods (1 day, 2 days and so on) after land application and at the end of each trial (2–3 weeks) was performed by analysis of variance (ANOVA).

RESULTS and DISCUSSION

Since the manure application rates were different for the spring 2005 trial versus the fall 2005 and spring 2006 trials, a comparison was made between the trials, via calculating the total amount of ammonia emitted, in turn, as a fraction of the initial mass of TAN and initial mass of TN present in manure. These ratios, which are expected to be different for the various trials, will be interpreted as ammonia emission factors.

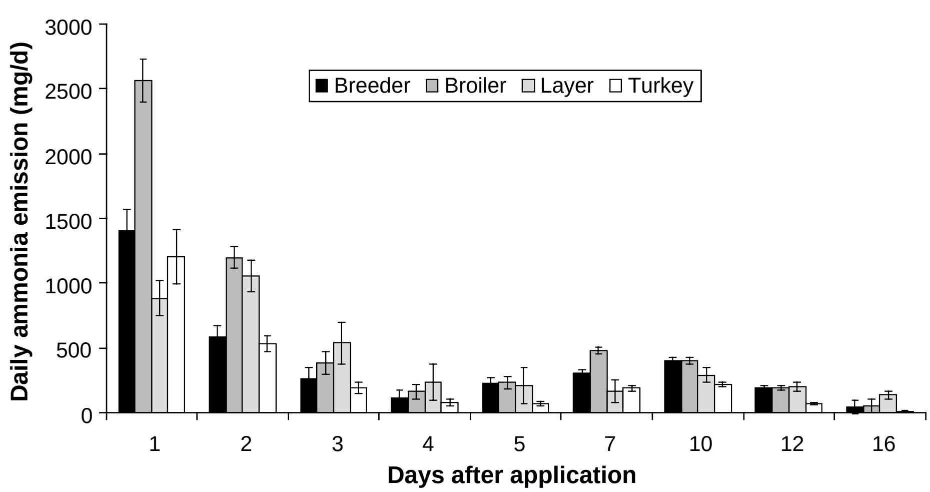

Fig. 1. Ammonia emission rates for four types of poultry manure – spring 2005 trial.

Ammonia emission profiles

Figure 1 shows the profiles of the daily ammonia emission rates (that is, rates of nitrogen losses as ammonia) along with the standard error bars that represent a 95% confidence interval for the spring 2005 trial data. Although they varied in the accumulated emissions over the 16-day period, all four poultry manures exhibited similar patterns of emissions with most ammonia being emitted over the first few days after manure application, then gradually declining though zero emission rates were not reached. The highest emission rates were 1405, 2560, 885 and 1200 mg d^{-1} m^{-2} for breeder, broiler, layer and turkey manure, respectively, on the first day. In fact, some 75% of the day 1 emission took place within the first 2 hours for breeder, broiler and turkey manure. Ammonia emission was positively correlated with pH and negatively correlated with TN, particularly in the first 2 hours. Statistical analysis via ANOVA indicated that total ammonia emissions were significantly different between the manure types ($p < 0.005$).

A similar emission pattern was evident in the fall 2005 trial (Fig. 2). 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. On day 1, ammonia emission rates were 1005, 655, 450 and 235 mg d^{-1} m^{-2} for breeder, broiler, layer and turkey manure, respectively. 70-75% of the day 1 emission occurred within the first 5 hours for all manure types. The relative magnitudes of ammonia emission rates among the manure types were consistently displayed until the end of the trial. There was a positive correlation between ammonia emission and pH ($r = 0.86$), while ammonia emission was 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 pH of 7.9 and 5.9 for layer and turkey manure, respectively.

As depicted in Fig. 3, a similar temporal pattern of emissions was again apparent for the spring 2006 trial. The exception is with turkey manure that lost less than 20% of the total ammonia emission during the first 3 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. 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, although emission from turkey manure exceeded the other manures on days 16 and 22 in the 2006 trial. Other manure types tended to have higher pH favoring early release of ammonia. The percent ammonia emissions relative to the initial amount of ammoniacal-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.

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.

The pattern of volatilization observed is consistent with the observations of Nahm (2005), that most of the uric acid would have been converted to ammonium within a few days of the in-barn storage of manure (before land spreading). However, the observations are in contrast to findings reported by Misselbrook et al. (2000) that ammonia emissions can persist for many weeks after land spreading of poultry manure because of the slow conversion of uric acid to ammonia. The exception in our trial was the turkey manure in the spring 2006 trial, which had generally increasing emission rates over the measurement period. An attempt was then made to measure the uric acid content of turkey manure. The procedure began by freeze drying the turkey manure to remove moisture and prevent further conversion of uric acid. Uric acid was then extracted from the manure using 1 M sodium carbonate for conversion into urate and subsequently centrifuged (Adeola and Rogler 1994; and personal communication with O. Adeola, Professor of Animal

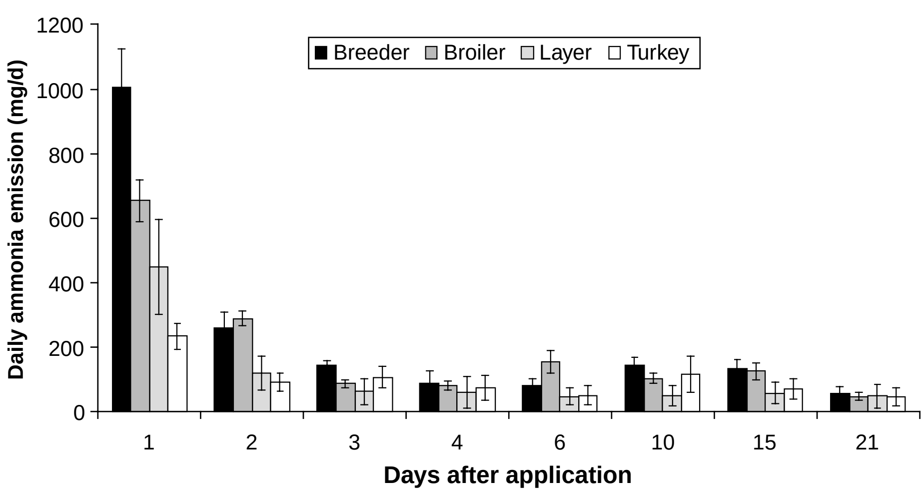

Fig. 2. Ammonia emission rates for four types of poultry manure – fall 2005 trial.

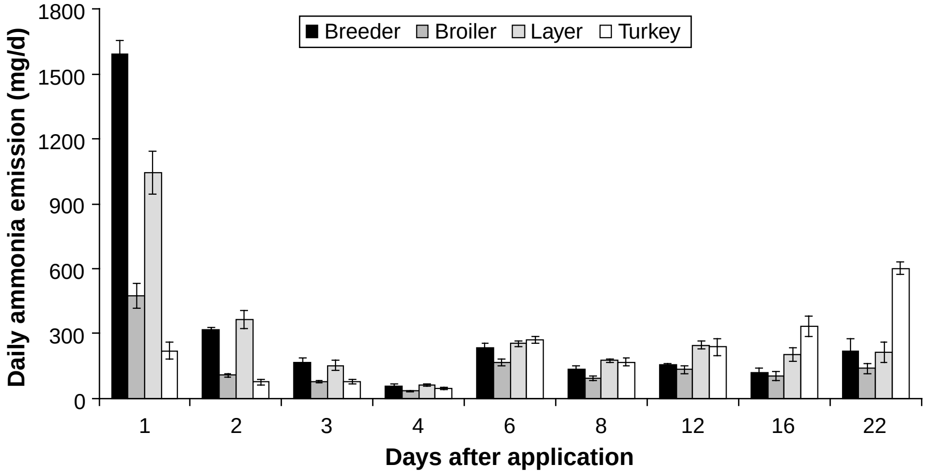

Fig. 3. Ammonia emission rates for four types of poultry manure – spring 2006 trial.

Sciences, Purdue University) and analyzed using a spectrophotometer (with optical density read at 590 nm) via the uric acid assay kit (BioAssay Systems, Hayward, CA). The analytical results indicated little uric acid was found in this manure (uric acid nitrogen content 0.23%), as compared with total nitrogen content of 5.95%. Nicholson et al. (1996) also reported a relatively low UAN (uric acid and NH_3-N) content of $<$0.1–1.1% (average 0.3%) versus TN content of 3.5–7.2% (average 5.2%). Thus, conversion of uric acid to ammonia days after land application might not be applicable, and the delayed emission could be due to the amount and type of bedding in this manure. This bears further investigation because a simple way to slow the release of ammonia will provide more opportunity for incorporation.

A summary of the cumulative percent total loss of NH_3 (relative to total loss at the end of the trial period) up to 1, 2, 3 and 7 days after manure application is presented in Table 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. (1997) had also pointed out that rapid incorporation of the manures following land spreading would reduce ammonia emissions by 35–63%. Sagoo et al. (2007) suggested rapid soil incorporation within 4–24 h via plowng was required to increase grass N uptake and reduce ammonia emissions by 15–87% compared with surface spreading.

Based on the combined results from all three trials, it may be concluded that the degree of correlation with pH is more significant ($p = 0.084$), when it is in terms of percent total loss of ammonia with time rather than the mass of ammonia emission. Ammonia emission has a negative correlation with TN to a lesser extent. There is practically no correlation between ammonia emission and other manure properties such as moisture content, TAN and TAN/TN ratio. It may be useful to develop a model for predicting the rate of release from relatively simple pH measurements, and taking into account environmental conditions, for the benefits of farmers.

Air temperature was consistently higher during the spring 2005 trial than the fall 2005 trial. The difference in temperatures ranged from 4.7 to 12.5°C in the first 48 hours after manure application, when emissions were the highest. The range of relative humidity was observed to be lower for the spring trial (50–100%) versus the fall trial (80–100%). Spring 2006 was also warmer than fall 2005. Ammonia emission rates, as previously displayed, were generally higher in both of the spring trials than the fall trial.

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

Type of manure	Day 1	Day 2	Day 3	Day 7
	% total loss	% total loss	% total loss	% total loss
Spring 2005 Trial				
breeder	40	57	64	82
broiler	45	66	73	89
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

*Cumulative percent total loss is 100% at the end of the sampling period in each trial

Table 3. Ammonia emitted as a fraction of initial TAN or TN in the three trials

		Spring 2005	Fall 2005	Spring 2006
Breeder	kg NH_3 kg^{-1} initial TAN	0.35 ± 0.03	0.85 ± 0.05	0.71 ± 0.05
	kg NH_3 kg^{-1} initial TN	0.09 ± 0.01	0.30 ± 0.02	0.20 ± 0.01
Broiler	kg NH_3 kg^{-1} initial TAN	0.57 ± 0.18	0.70 ± 0.07	0.46 ± 0.10
	kg NH_3 kg^{-1} initial TN	0.12 ± 0.03	0.12 ± 0.01	0.09 ± 0.02
Layer	kg NH_3 kg^{-1} initial TAN	0.37 ± 0.10	0.40 ± 0.04	0.33 ± 0.06
	kg NH_3 kg^{-1} initial TN	0.23 ± 0.06	0.06 ± 0.01	0.18 ± 0.03
Turkey	kg NH_3 kg^{-1} initial TAN	0.33 ± 0.04	0.26 ± 0.02	0.65 ± 0.09
	kg NH_3 kg^{-1} initial TN	0.16 ± 0.02	0.10 ± 0.01	0.14 ± 0.02

Ammonia emission factors

Calculated ammonia emission factors are depicted in Table 3. It can be seen that the cumulative ammonia emission in all treatments did not exceed the initial amount of TAN present in manure for all trials. The ammonia emission factors demonstrate variations among the various types of poultry manure. 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 (gradual decrease in ammonia emission rate with time) during all trials.

Revised ammonia emission factors are being proposed on the basis of the findings from this study, and they are presented in Table 4. These values were obtained by taking the average values of the emission factors from all trials. The current values of emission factors as adopted by Environment Canada (2005) are also shown in Table 4 for comparison purposes. For the two major types of poultry - broiler and layer, current emission factors of 0.11 and 0.15 (TN basis) are very close to the proposed revised values of 0.12 and 0.16, respectively. The magnitudes of the emission factors based on percent of total nitrogen (% TN) are comparable with findings from other research studies, for instance, 0.033–0.24 (Sharpe et al 2004) and 0.135 for broiler litter without incorporation (Rodhe and Karlsson 2002). For the turkey manure, there was a large difference between the current and revised emission factor value of 0.38 and 0.13, respectively. The revised value of 0.13 is similar to broiler manure, as both types of poultry use a lot of bedding materials.

CONCLUSIONS

Based on the field trials conducted under in 2005 and 2006, total ammonia emissions based on TN and TAN were significantly different among manure types ($p < 0.005$), but the ranking changed with trial. In almost every case, the highest emission rate occurred in the first day after application, and gradually declining in the 2- to 3-week period towards the end of the trial. By cultivating the manure within 24 h, emission reduction of over 50% might be achieved, but a delay of 48 h would usually lead to a reduction of only 35–40%. The application rate of 470 kg TN ha^{-1} in spring 2005 was greater than the application rate of 150 kg TN ha^{-1} for the fall 2005 and spring 2006 trials; hence, the generally higher ammonia emission rates observed in both of the spring trials than the fall trial could be attributed more to temperature differences than the differences between the application rates.

Despite the variations of TAN content and TN content in the different 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 attributed to its pH value being lower than 6, which is not favorable for ammonia volatilization. Cumulative ammonia emission in all treatments did not exceed the initial amount of ammonia-nitrogen present in manure, suggesting that the conversion of uric acid to ammonia after land application might not be significant for the manure used in these trials.

The quantity of ammonia emitted within 24 hours (day 1), expressed as a percentage of the total ammonia

Table 4. Comparison of current values and proposed revised values of ammonia emission factors*

	Current values kg NH_3 kg^{-1} initial TAN (based on TAN)	Revised values kg NH_3 kg^{-1} initial TAN (based on TAN)	Current values kg NH_3 kg^{-1} initial TN (based on TN)	Revised values kg NH_3 kg^{-1} initial 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	0.41	0.38	0.13

*Current values, currently adopted by Environment Canada (2006), Revised values, derived from this study.

emission over the duration of each trial, was found to be 48, 41, 38 and 29% for breeder, broiler, layer and turkey manure, respectively. In fact, most of the day 1 emission 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. Such information would be 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 0.13, respectively. The revised value of 0.13 is similar to broiler manure, as both types of poultry use a lot of bedding materials; the higher carbon content of the bedding material may have caused the immobilization of available nitrogen and delayed ammonia emission after land spreading. It may also be attributed to the high nitrogen content of the turkey manure used in all trials of this project.

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