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The development of seasonal emission factors from a Canadian commercial laying hen facility

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HIGHLIGHTS

- A study was conducted at a layer facility in Wellington County, Ontario, Canada.
- The average ammonia emission factor was 19.53 ± 19.97 g day^{-1} AU^{-1}.
- Ammonia emissions were largely influenced by excreta cleanout times.
- PM emissions were heavily influenced by the bird activity level and photoperiod.
- The $PM_{2.5}/PM_{10}$ ratio was determined to be seasonally dependent.

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ABSTRACT

Pollutants emitted from poultry housing facilities are a concern from a human health, bird welfare, and environmental perspective. Development of emission factors for these aerial pollutants is difficult due to variable climatic conditions, the number and type of poultry, and the wide range of management practices used. To address these concerns, a study was conducted to develop emission factors for ammonia and particulate matter over a period of one year from a commercial poultry laying hen facility in Wellington County, Ontario, Canada.

Instruments housed inside an on-site mobile trailer were used to monitor in-house concentrations of ammonia and size fractionated particulate matter via a heated sample line. Along with a ventilation profile, emission factors were developed for the facility. Average emissions of 19.53 ± 19.97, 2.55 ± 2.10, and 1.10 ± 1.52 g day^{-1} AU^{-1} (where AU is defined as an animal unit equivalent to 500 kg live mass) for ammonia, PM_{10}, $PM_{2.5}$, respectively, were observed. All emissions peaked during the winter months, with the exception of $PM_{2.5}$ which increased in the summer.

1. Introduction

Intensive poultry operations can be a significant source of harmful atmospheric pollutants such as ammonia (NH_3) and size-fractionated particulate matter (PM). Ammonia, from a human health and bird welfare perspective, is of interest due to the fact that it has been identified as a severe respiratory tract irritant (Anderson et al., 1964). Ammonia has also been designated as a toxic substance by Environment Canada (Environment Canada, 2012a). $PM_{2.5}$ (particulate matter with aerodynamic diameter of 2.5 μm or less) inhalation has been linked to impaired lung function and size fractions up to PM_{10}, have been linked with an increased risk of mortality from long term exposure (Schwarze et al., 2006). Ammonia is also a precursor gas for the formation of ammonium salt aerosols, which contribute to the $PM_{2.5}$ size fraction (Lin et al., 2012b).

The agriculture sector accounts for the majority of ammonia emissions to the atmosphere in Canada, while only contributing relatively small quantities of size fractionated particulate matter (Environment Canada, 2012b). The National Pollution Release Inventory (NPRI) (Environment Canada, 2012b) uses constant emission factors to estimate the quantities released from agriculture. Previous studies in broiler facilities (Wathes et al., 1997; Groot Koerkamp et al., 1998; Wheeler et al., 2006; Burns et al., 2007; 2008; Gates et al., 2008; Roumeliotis et al., 2010a; b; Lin et al., 2012a), however, have shown that emissions of NH_3 and PM are seasonally dependent in a temperate climate. There are limited corresponding seasonal studies with laying hens and hence the aim of the current study is to assess the seasonal behavior of NH_3 and PM emissions from a commercial laying hen facility.

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The majority of laying hen facilities use battery cages although perchery and free range housing systems are becoming more common (Thiele and Pottguter, 2008). The two prominent manure systems for caged birds are manure pits (deep pit) and automated manure belts. In the high rise deep pit configuration, the battery cages are situated over an open manure storage system while, in houses with a manure belt system, a large belt is located beneath each cage to convey manure to a secondary storage location, usually outside of the house. Currently, in the United States, 70% of laying hen facilities use the high rise with a deep pit system and the remaining 30% use the high rise with a manure belt configuration. Most new laying hen facilities, however, are opting for the manure belt system (Xin et al., 2011).

Typically, facilities using deep pit systems have poorer air quality and emit more ammonia than facilities using a manure belt management system (Green et al., 2009). The frequency with which manure belts are used to remove excreta greatly reduces the amount of ammonia emitted from the facility compared to high rise systems with a deep pit (Liang et al., 2005). In non-caged systems, the emission of ammonia and PM are typically higher than facilities using a caged system (Xin et al., 2011).

Several studies have focused on developing emission factors for ammonia and/or PM for laying hen facilities (for examples see: Hartung and Phillips, 1994; Phillips et al., 1995; Wathes et al., 1997; Groot Koerkamp et al., 1998; Yang et al., 2000; Keener et al., 2002; Jacobson et al., 2004; Nicholson et al., 2004; Heber et al., 2005; Liang et al., 2005; Lin et al., 2012b; Ni et al., 2012; Li et al., 2013; Wang-Li et al., 2013). Accurate and representative quantification of atmospheric pollutants from a poultry production facility can be difficult to obtain. This is due to variable climatic conditions depending on geographic location, the number and type of poultry, and the wide range of management practices that are employed. Management practices include feeding, watering and lighting regimens, manure removal and storage systems, and ventilation systems. Commercial poultry production can thus be highly variable and studies should be conducted to include a diverse combination of different poultry species, management practices, and geographic locations. This will give governments, facility operators, and commodity groups a scientifically sound interpretation of the behavior of the pollutants emitted from poultry production facilities.

2. Materials and methods

The commercial laying hen facility used for the study was located in Wellington County of Ontario, Canada. The facility was comprised of two identical barns that housed between 65,000 and 70,000 laying hens per barn. Each two story barn had a caging area of approximately 123 m by 12 m. On each floor, there were four rows of cages running the length of the barn, and each row had three levels of caging. Approximately 8832 cages were located inside each barn, each cage holding a maximum of 8 birds. This allowed for a maximum stocking density of 474 cm^2 $bird^{-1}$.

Periodically, throughout the production cycle, 64 birds were weighed to obtain an average bird mass. Using the total number of birds and the calculated average bird mass, the total mass of the birds in the house was estimated. The total number of birds at week 1 of the production cycle was 70,600 with an average of 40 mortalities each week from various causes. During the 34th week of the production cycle, 1776 birds were culled.

Mechanical ventilation was used to regulate the temperature within the facility using: fourteen × 0.61 m, four × 0.91 m, twelve × 1.22 m, and six × 1.37 m diameter fans. All 0.61 m diameter fans were variable speed, with the remainder being single speed on/off fans. Depending on the season, the indoor temperature was maintained between 18.9 and 22.2 °C. The ventilation controller used an eight stage ventilation program that varied the air flow of the facility from a cross ventilated system in the cooler months to a hybrid tunnel ventilated system during the warmer months. The maximum ventilation rate for the facility was approximately 158 m^3 s^{-1}.

The ventilation system was based on the difference between the average indoor temperature and the set point temperature. The average indoor temperature was recorded using 8 evenly spaced temperature probes. For the cross ventilation system, fresh air inlets were located on either side of the facility using 3.05 m length baffles running the full length of the barn. Under the hybrid tunnel ventilation configuration, the fresh air inlets used were located at the south end of the facility.

The lighting regimen began with 13.5 h of light per day starting at 06:00 for new flocks. After 20 weeks had elapsed, 15 min of light was added per week to a maximum of 16 h per day, typically occurring by the 30th week of the 53 week production cycle. Feed was delivered to feed trays by an automatic feeder auger, and water by nipple drinkers. Birds were fed an industry standard diet for laying hens. Manure belts were located underneath each level of cages and were run twice a week on Tuesday and Friday. Manure cleanout times were consistently between 10:30 and 11:30. Floors were swept by staff to remove dust on an as needed basis.

For this geographic region, data was collected during periods typifying Fall, Winter, Spring, and Summer. Although the four sampling campaigns do not completely cover each season they are deemed representative of the time period. The period from November 6th, 2010 to December 15th, 2010 was considered the Fall collection season, Winter data was collected from February 19th, 2011 to March 20th, 2011 and the Spring collection period was April 26th, 2011 to May 11th, 2011. During the month of July (2011) the facility was depopulated and a new flock was started. This occurred before the Summer data collection period which spanned August 9th, 2011 to September 12th, 2011.

3. Instrumentation

Ammonia concentrations were continuously monitored using a chemiluminescent ammonia analyzer (Model 17I, Thermo Electron Corporation, Franklin, MA, USA). A climate controlled mobile trailer unit was used to house the analyzer and support gases outside the facility. The calibration was evaluated on a weekly basis with a 25 ppm ammonia calibration gas balanced with air. A 5 min logging interval was used with a 10 s time constant. Sample air was drawn from the facility to the trailer through a heated sample line at 121 °C (Model 0723-100, Clean Air Engineering Inc.) to prevent condensation within the air stream prior to entering the analyzer.

PM concentrations were continuously monitored using two DustTrak aerosol analyzers (Model 8520, TSI Incorporated, Shoreview, MN, USA). Each analyzer was equipped with an inlet nozzle using either 10 μm or 2.5 μm cut size. The analyzers were factory calibrated using a standardized test dust (ISO 12103-1 A1 Arizona Road Dust), which differed significantly from that of the facility and hence dust samples were collected to adjust the calibration density. A bulk density test was used to determine the density of the dust specific to the facility. A correction factor was developed using the ratio of the measured density to the calibration density and was applied during the data analysis. The aerosol monitors were housed inside the facility collecting samples from the same location as the inlet for the heated sample line used for ammonia. Both PM monitors were set to a 5 min logging interval with a 15 s time constant.

A single sampling location was used throughout the study for both the PM and NH_3 monitors, located approximately 85 m from the south end of the facility on the west facing side of the building. The sampling location was located horizontally 1.0 m away from a