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Abstract

The contribution of agricultural emissions of primary (direct) and secondary (precursor) pollutants to air quality is rapidly being recognized as an important fraction of local and regional air pollution budgets. However, a significant uncertainty still exists in the magnitude and rate of these types of emissions, especially under "in field" conditions common within the central and western United States. Described herein are the results of a study conducted at a deep-pit swine production facility in central Iowa. The facility consisted of three separate, parallel barns, each housing around 1,250 pigs with an average weight of approximately 90 pounds per animal. The area around the facility was topographically flat and surrounded by soybean and cornfields. A number of portable $PM_{10}/PM_{2.5}$ (AirMetrics MiniVol) samplers and passive NH_3 (Ogawa Model 3300) samplers were arrayed vertically and horizontally around the three-barn production facility, and data were collected on a daily-averaged basis for approximately three weeks in August and September of 2005. Additionally, a monitoring station was established approximately 40 m to the north of the nearest barn to record the typical suite of meteorological parameters (wind speed, direction, temperature, etc.) for determination of near-source atmospheric advection and dispersion. The AirMetrics samplers were operated with $PM_{2.5}$ impactor separation heads for approximately the first half of the field study and were then switched to the PM_{10} heads for the remaining portion of the study. Each AirMetrics sampler was fitted with a conditioned, preweighed Teflon filter and operated at approximately five liters per minute for a time-controlled 23-hour period. Following sampling, the filters were recovered, conditioned, and reweighed at USU's Utah Water Research Laboratory (UWRL) in Logan, UT for filter catch and ultimate determination of each location's $PM_{2.5}/PM_{10}$ mass concentration. The Ogawa passive samplers were co-located and operated for the same time periods with the pre-treated (acid-coated) collection pads recovered after the same 23-hr period and stored appropriately until the final analysis for NH_3 concentrations could be performed via ion chromatography at the UWRL facility. Emission estimates were derived via the comparisons of the measured particulate and NH_3 concentrations at each sampling location with the concentrations for each receptor (sample) point found via application of the EPA-recommended ISCST3 air dispersion model (Lakes Environmental Software). The comparison of the measured and model predicted NH_3 concentrations resulted in a derived NH_3 emission rate of 17.22 ± 7.2 g/pig/day. This value is slightly more than two times greater than referenced emission rates; however, the two emission rates are within statistical uncertainty of each other. The analyses for the particulate emissions are as yet incomplete; however, preliminary calculations show PM_{10} and $PM_{2.5}$ emission rates of 0.55 and 0.14 g/pig/day, respectively.

Introduction

The existence of fine particulate matter in the atmosphere is the result of a complex combination of direct source (primary) emissions and photochemical (secondary) formation reactions. In broad terms, the composition of fine particulate, typically defined as $PM_{2.5}$ or suspended particulate matter with a diameter of less than 2.5 μm, is often broken into five basic categories: (1) crustal elements, (2) organic carbon, (3) elemental carbon, (4) ammonium sulfate, and (5) ammonium nitrate (Malm, 2000). The significance of any particular compositional element is often a strong function of locally dominant source categories.

The contribution of agricultural emissions of primary (direct) and secondary (precursor, especially ammonia) pollutants to air quality has only recently been recognized as an important fraction of local and regional air pollution budgets (Bicudo et al., 2002). However, a significant uncertainty still exists in the magnitude and rate of these types of emissions, especially under "in field" conditions common within the

central and western United States (CENR, 2000; FAO, 2001; CAEAFO, 2002). As such several local and regional agricultural emission projects have been reported over the last few years (Hoff et al., 2005; Heber et al., 2005; and others).

As a part of a larger field investigation (Bingham et al., 2006; Zavyalov et al., 2006; and others), studies described herein were conducted at a swine finishing facility near Ames, Iowa to examine the facility-wide emissions of PM_{10} and $PM_{2.5}$ and gas-phase ammonia (NH_3) using arrayed field measurements of the target species, followed by subsequent inverse modeling using an EPA-approved Gaussian dispersion model.

Methodology

The field measurements took place from August 24 to September 7, 2005. A three-barn, deep-pit swine finishing operation located near Ames, Iowa was the site selected for the study. Each barn housed approximately 1,250 pigs, with an average weight during the test period of 90 pounds. The barns were 21.8 m apart, all aligned in a parallel east-west orientation, with each barn being 12.6 m wide and 79.5 m long. A 1.4 m tall screen-vented window ran long the north and south sides of the barns. These windows were equipped with retractable canvas shades, but these were rarely employed throughout the duration of the test.

Based on historical meteorological data, portable $PM_{2.5}/PM_{10}$ and NH_3 samplers were deployed in a generally north-south array in and around the facility. Most of the samplers were deployed on tripod supports at a height of about 2 m above ground level (see Figure 1). Additionally, elevated samplers were placed on a meteorological tower between two of the barns and on a second tower in a cornfield to the north of the facility.

Figure 1. Particle and NH_3 samplers near pig barn

The particle samplers used were AirMetrics MiniVol $PM_{2.5}/PM_{10}$ samplers. These samplers are self-contained (particle collection mechanism, pump/flow control, and battery) and can be programmed to operate for any desired time period. The MiniVols separate for PM_{10} or $PM_{2.5}$ depending on which fractionation head is installed on the unit. The particulate matter was collected on pre-weighed Teflon filters, which were transported back to Utah State University (USU) for final weight determination and concentration determination. From August 24 to September 1, the systems were configured to sample for $PM_{2.5}$; during the remaining test periods the samplers were configured for PM_{10}.

Ambient ammonia concentrations were monitored via passive sampling monitors described by Roadman et al. (2003). The samplers consist of a citric acid-treated quartz fiber pad, a series of diffusion screens, an

inert housing, and a rain shield. The samplers were exposed at the arrayed locations for a recorded period of time and recovered into air-tight containers. The pads were then transferred to individual sampling bottles until they could be returned to USU for NH_3 analysis using ion chromatography.

The sample collection periods were broken into 23-24 periods for each system. In addition to the pollutant measurements ,on-site meteorological data were also collected. Emission points (barns) and sampler locations were all recorded using a hand-held GPS system.

The pollutant concentrations, source/receptor locations and meteorology were used in conjunction with the U.S. EPA's Industrial Source Complex, Short Term (ISCST3) Gaussian plume dispersion model to back calculate the emissions required to observe the monitored pollutant concentrations. The specific software used was the ISC-AERMOD package marketed by Lakes Environmental Software. In brief, the model was operated for the chosen time period, using observed meteorology and a "seed" value for the initial emission rates. After several approaches it was determined that treating the barns as volume sources most reliably produced results similar to the observed concentrations. The initial emission rates were obtained from those reported by other investigators for similar facilities (Hoff et al.; 2005). The initial NH_3 emission rate was assumed to be 7.43 g/pig/day, while the initial PM_{10} and $PM_{2.5}$ emissions were assumed to be 0.11 g/pig/day and 0.028 g/pig/day (since no separate value was given for $PM_{2.5}$, its emission rate was assumed to be 25% of the PM_{10} rate). Modeled concentrations at the specified receptor (sampler) locations were then compared to the observed values. The ratio of the observed values to the modeled values were then compiled and used as a multiplier for the "seed" emission rate to derive the on-site specific value.

Results and Discussion

The observed ammonia concentrations ranged from 6.8 $\mu g/m^3$ farthest or upwind from the barns to 905 $\mu g/m^3$ nearest the barns. Samplers that were determined to be upwind or completely crosswind from the source, and therefore not affected by barn-generated emissions, were treated as local/regional background samples and subtracted from the barn-impacted samples. The average NH_3 background sample was found to be around 25.7 $\mu g/m^3$. The elevated locations (met towers) generally showed lower concentrations than samplers posted on the same towers but at lower elevations.

Overall, the modeled NH_3 concentrations were on the same order as the observed values, with a few notable exceptions. The model was unable to adequately account for plume buoyancy and nearly always under-predicted the concentrations at the elevated receptor locations. Furthermore, the concentrations predicted by ISCST3 for the upwind or crosswind areas were usually zero or much less than 1$\mu g/m^3$, which also led to much smaller values than observed for those receptors.

The under prediction of the modeled concentrations for the extreme receptor locations resulted in anomalously large concentration ratios (measured over modeled) for these fringe sites (see Figure 2). If all of the receptor/sample locations are included, the overall average NH_3 concentration ratio was found to be 44.0 ± 52.6 (the uncertainty represents the 95% confidence interval). This would mean that the derived emission rate would need to be 44 times the assumed "seed" emission rate of 7.43 g/pig/day.

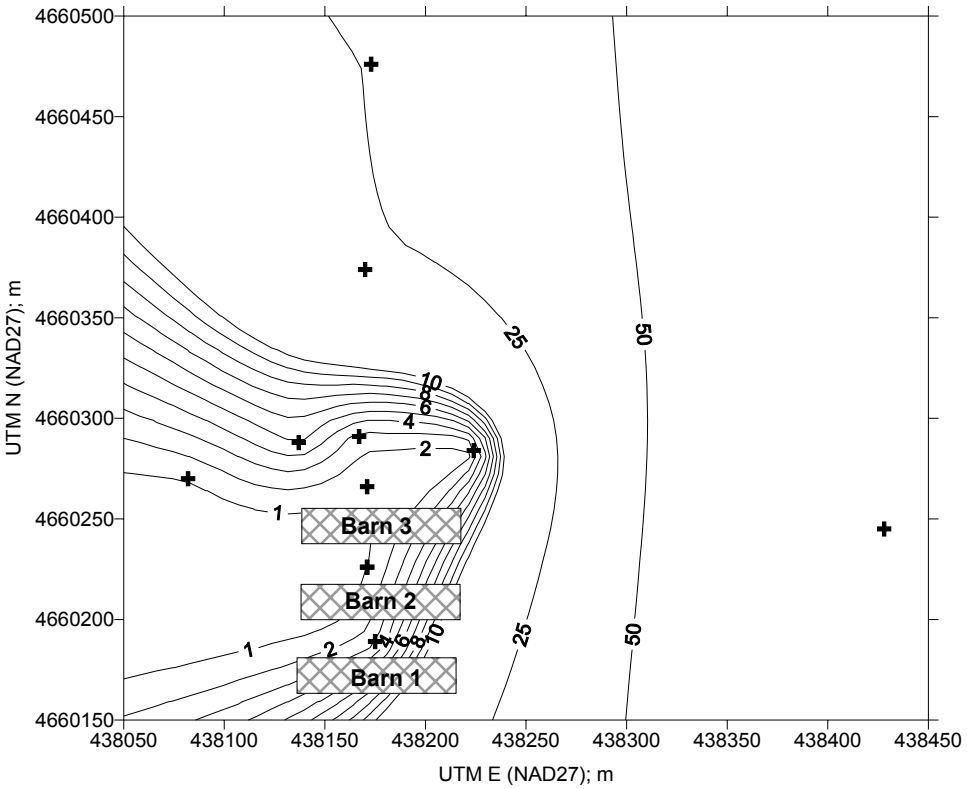

Figure 2. Isoplethic map of the overall averaged ratio of the observed NH_3 concentrations to the modeled NH_3 concentrations.

A more realistic NH_3 emission rate can be derived, however, if the elevated and non-plume receptor points are ignored. By discounting the under-predicted locations, essentially all points outside of the "6" isopleth in Figure 2, the average concentration ratio (measured to predicted) becomes 2.32 ± 0.96, which equates to an average emission rate of 17.2 ± 7.2 g/pig/day. This value is higher than, but statistically indistinguishable from, that of Hoff et al. (2005).

The data for the particulate measurements and modeling are, as of this writing, still incomplete. However, preliminary analysis suggests that arrayed, mass-based field measurements may not be the best way to quantify particulate emissions from this specified type of agricultural facility. Background, non-barn influenced PM_{10} and $PM_{2.5}$ concentrations were found to average around 35 and 10 μg/m^3, respectively, while in-plume values were 40-60 and 10-15 μg/m^3, respectively, depending on sampler location relative to the barns. This suggests approximately 15 μg/m^3 of the nearby atmospheric PM_{10} may be attributable to the swine houses. Similarly, up to 5 μg/m^3 of the local $PM_{2.5}$ may be attributable to the examined sources.

ISCST3, using Hoff et al.'s (2005) PM_{10} emission rate of 0.11 g/pig/day, predicted barn-induced PM_{10} contributions in the range of 0.62-3.48 μg/m^3, depending on the receptor location. Scaling the emission rate for $PM_{2.5}$ results in expected fine particle concentrations in the range of 0.02-0.81 μg/m^3. These numbers suggest the model-derived particulate emission rates are greater than five times the initial "seed" values. This would give PM_{10} and $PM_{2.5}$ emission rates of 0.55 and 0.14 g/pig/day, respectively.

Conclusions

The approach of coupling field-arrayed concentration measurements and inverse Gaussian modeling proved to be a valid and reasonable approach for modeling gas-phase ammonia emissions from the examined three-barn, deep-pit swine finishing facility (3,750 total animals). The derived NH_3 emission rate of 17.22 ± 7.2 g/pig/day was slightly more than a factor of two greater than the referenced emission rate (Hoff et al., 2005), but within the range of statistical uncertainty.

Owing to the expected low emission rates of the particulate matter, the observed differences between the local/regional background PM_{10} and $PM_{2.5}$ made determination of robust emission rates difficult. However, the ISCST3 model did demonstrate that the three swine barns were not an overly strong source of ambient particle. Preliminary analysis estimated PM_{10} emissions of 0.55g/pig/day and $PM_{2.5}$ emissions of 0.14 g/pig/day. Due to the limitations discussed previously no statistical uncertainties can be calculated at this time.

For facility-wide particle emissions, when the facility cannot easily be enclosed or otherwise encapsulated for direct flux measurements, techniques other than mass-based methodologies may need to be examined. These may include LIDAR systems or field-arrayed measurements similar to those described herein, but would need to utilize particle counters as opposed to filter collection.

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