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Evaluation and application of a dynamic emissions chamber for quantifying gaseous emissions from laying hen manure

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Abstract

The need to quantify air emissions from animal feeding operations (AFOs) with relative ease and reasonable certainty continues to rise. Exploration of practical means to reduce air emissions also calls for less sophisticated but reasonably dependable methods to quantify the treatment effect. Although mobile air emissions monitoring units (MAEMUs) capable of precise and real-time emission measurement is the norm for continuous, intensive monitoring of emissions from mechanically ventilated animal facilities, their relative immobility and high cost are limiting their widespread use. Several other methods, such as gas-washing, micro-meteorological, wind tunnel, flux chamber, and mass-balance methods, have been employed to accommodate different measurement needs. Flux chambers have the advantages of being portable, small size, low cost, and less labor requirement. However, the performance of flux chambers and thus the measured emission values may be subject to the influence of the system design and operational characteristics. The focus of this study was on the evaluation and application of a dynamic flux chamber (DFC) for quantifying NH_3 and CO_2 emissions from laying hen manure.

The first objective, as reported in Chapter 2, was to assess the impact of operational parameters on the DFC, including: air exchange rate expressed in air changes per hour (ACH), and air turbulence or velocity over the manure surface resulting from different air inlet angles into the DFC space. Results of laboratory tests with laying-hen manure revealed that measured NH_3 and CO_2 emissions are positively related to DFC air exchange rate. Higher air velocities (0.07 *vs.* 0 $m \cdot s^{-1}$ at 39 ACH) over the manure surface as a result of the different air inlet angles (0 *vs.* 45 degrees) were shown to positively affect the measured gaseous emissions.

The second objective, as reported in Chapter 3, was to assess gaseous (NH_3 and CO_2) emissions of high-rise layer houses as measured with the DFC *vs.* MAEMU. The preliminary data showed that NH_3 emission from the stored manure surface or piles measured with the DFC was 8% to 16% that of the whole barn measured with the MAEMU, while CO_2 emission from the manure surface was 1% to 4% of the barn emission. The preliminary results obtained with DFC concerning the dietary efficacy of ammonia emission reduction were mixed as compared to those obtained with the MAEMU.

Chapter 1: General Introduction

Introduction

Ammonia (NH_3) and carbon dioxide (CO_2) are two major gases produced from animal feeding operations (AFO). NH_3 is generally considered the major pollutant released, while CO_2 the principal greenhouse gas (GHG). Of primary interest is the reporting requirement from the Emergency Planning and Community Right-to-Know Act (EPCRA) if an animal production facility exceeds the 100 lb/day threshold of a hazardous material. NH_3, along with H_2S is generally considered the limiting hazardous gas compound from AFOs (Jacobson et al., 2005). Additionally, the U. S. Environmental Protection Agency (EPA) is expected to regulate CO_2 and other GHGs (Broder, 2009).

Although NH_3 emission regulations have been in place for some time, state and federal regulatory agencies have not enforced these regulations for animal operations for various reasons including the limited information on emission of gaseous pollutants for animal facilities (Jacobson et al., 2005). However, regulatory entities are being pushed to enforce these standards, thus the need for reliable methods to monitor emissions arises.

Mobile air emissions monitoring units (MAEMUs) are capable of precise and real-time emission measurement and are typically used for continuous, intensive monitoring of emissions from mechanically ventilated animal facilities. It involves measurement of airflow rate of the exhaust or supply fans under specific static pressure and monitoring fans run-time. Among the studies that involve use of MAEMUs is the comparison of dietary treatments in terms of their impacts on gaseous emissions. In spite of the MAEMU's precision and real-time measurement capabilities, its relative immobility and high cost limits the widespread use for baseline emission and mitigation studies. Flux chambers have the advantages of being portable, small size, low cost, and less labor requirement.

The performance of flux chambers and thus the measured emission values may be subject to the influence of the system design and operational characteristics. It has been documented that flux measurements from urea in the soil are affected by air exchange rate (Kissel et al., 1977; Whitehead and Raistrick, 1991; Rhoades et al., 2005). In addition, several other studies have shown improvement in NH_3 emission estimation from wind tunnel and flux methods by matching air velocities over the emission source area to actual conditions (Ryden and Lockyer, 1984; Blanes Vidal et al., 2006; Wheeler et al., 2007).

The focus of this study was on the evaluation and application of a dynamic flux chamber (DFC) for quantifying NH_3 and CO_2 emissions from laying hen manure. The first objective, as reported in Chapter 2, was to assess the impact of operational parameters on the performance of a DFC, including: air exchange rate expressed in air changes per hour (ACH), and air turbulence or velocity over the manure surface resulting from different air inlet angles into the DFC space. The second objective, as reported in Chapter 3, was to assess gaseous (NH_3 and CO_2) emissions of high-rise layer houses with the DFC *vs.* MAEMU. The second part of the study was conducted at a commercial farm in central Iowa, where three mechanically ventilated high-rise laying-hen houses under three different dietary regiments (EcoCal^{TM}, DDGS and Control) were monitored by a MAEMU.

Thesis Organization

This thesis has been prepared in ASABE journal paper format, consisting of two manuscripts. The thesis includes four chapters − a General Introduction, one manuscript entitled “Effects of Air Flow Rate and Inlet Angle of a Dynamic Flux Chamber on Measurement of NH_3 and CO_2 Emissions from Laying-Hen Manure,” another manuscript entitled “Evaluation of a Flux Chamber for Assessing Gaseous Emissions and Treatment Effects of Poultry Manure,” and a General Conclusion. In addition an appendix is included with additional information pertaining to the thesis research.

Literature Review

Animal feeding operations

An animal feeding operations (AFO) as defined by the U.S. Environmental Protection Agency (EPA) is a lot or facility where (1) animals have been, are, or will be confined and maintained for a total of 45 days or more in any 12 month period, and (2) crops, vegetation, forage growth, or post harvest residues are lacking. The absence of vegetative cover of any significance excludes operations where animals are maintained on pasture or rangeland. In addition, the definition excludes any aquatic animal production facility. An AFO includes the confinement facility, manure management systems, and the manure application site (CFR, 2005).

Around the 1950s a change in traditional methods of how farm animals were raised began to occur. There was a development of new confinement systems that generally kept animals in specialized indoor environments and used hardware and automation instead of labor for many routine tasks. Confinement methods became predominant for species that are largely fed on grain and other concentrated feed, notably in the production poultry, pigs, veal calves and eggs (Fraser, 2005). These methods were accompanied by large increases in production.

Gaseous Emissions

The substances and quantities emitted by an AFO can vary substantially, depending on the design and operation of each facility. AFOs can emit ammonia (NH_3), nitrous oxides (N_2O), hydrogen sulfide (H_2S), carbon dioxide (CO_2), methane (CH_4), total reduced sulfur (TRS), volatile organic compounds (VOC), hazardous air pollutants (HAP), and particulate matter (including PM_{10} and $PM_{2.5}$). Gaseous emissions can be influenced by many factors such as animal species, number of animals present, type of confinement facility, feeding regiment, type of manure handling and storage system, phase of production, and time of year (EPA, 2001). Most gaseous emissions of AFOs are generated by the decomposition of livestock wastes such as manure (feces and urine), spilled feed, bedding materials and wash water (Jacobson et al., 2003).

NH_3 is produced through the microbial decomposition of the organic nitrogen compounds in manure. Nitrogen in the diet that is not fully converted to animal products occurs as either urea (mammals) or uric acid (poultry) in urine, which hydrolyze rapidly to form NH_3. Emission will continue with the microbial breakdown of manure under both aerobic and anaerobic conditions. Because NH_3 is highly soluble in water, it will accumulate in manure handled as liquids and semi-solids or slurries, but will volatize rapidly with drying from manures handled as solids. CO_2 also occurs as a consequence of microbial degradation of organic matter under both aerobic and anaerobic conditions. Under aerobic conditions, essentially all of the carbon is emitted as CO_2. Under anaerobic conditions, CO_2 is one of the by- products of the microbial decomposition of organic matter to methane. Thus, both NH_3 and CO_2 occur wherever manure is present (EPA 2001).

In the past gaseous emissions from agriculture were exempt from regulation. Its vital role in society and lack of resources to measure actual emissions provided a degree of amnesty for AFOs. In 2001 the EPA submitted a report on "Emissions from Animal Feeding Operations," which had as one of the objectives to assess the value of available information to support future air pollution policy decisions regarding AFOs. The report summarized existing gaseous emission records and recognized various data gaps to develop a complete set of emission estimates for model farms.

Monitoring systems

Several methods for monitoring gaseous emissions, such as gas-washing, micro-meteorological, wind tunnel, flux chamber, and mass-balance methods have been employed to accommodate different measurement needs (Koziel et al., 2005; Liu et al., 2008). Gas-washing consists of wet laboratory analysis with a scrubber system, which provides measurements of average concentrations over a relatively long period of time (hours or days). Gaseous emission fluxes can be calculated from measured concentration and corresponding house ventilation rate (Liu et al., 2008). Micro-meteorological methods involve the determination of the difference in gas amounts carried by the wind through the vertical planes (Ryden and Lockyer, 1984). These methods are commonly used to correlate gaseous emissions with climatic and emission source factors (Ferguson et al., 1987). The wind tunnel approach consists of an enclosed vessel that applies a certain velocity over a given area that is similar to actual conditions. Emission flux is calculated by relating gas concentrations to the flow rate through the vessel (Kinbush, 1985). Emissions from flux chamber methods are similarly calculated and consist of applying a given flow rate over an enclosed volume and measuring gas concentrations with an analyzer. In a mass-balance approach the average emission fluxes can be estimated from total nutrient losses of an emission source throughout a concerned period (Liu et al., 2008). This method is commonly used to estimate NH_3 emissions from nitrogen sources.

The standard for gaseous emissions monitoring is the mobile air emissions monitoring units (MAEMUs), capable of precise and real-time emission measurement and typically used for continuous, intensive monitoring of emissions from mechanically ventilated animal facilities. Gaseous emission rate (ER) is quantified as the product of concentration difference (between exhaust and inlet air) of the pollutant and the ventilation rate (Q) through the facility or source (Li et al., 2008b). It involves measurement of airflow rate of the exhaust or supply fans under specific static pressure and monitoring fans run-time. In spite of the MAEMU's precision and real-time measurement capabilities, its relative immobility and high cost limits the widespread use for baseline emission and mitigation studies.

Mitigation strategies

The facility design and operating methods may influence gaseous emissions. For example NH_3 and other gaseous emissions can be reduced by removing solids more frequently (ever y 7 days or more often). Several methods have been developed to reduce gaseous emissions from AFOs. These address three major areas, (1) manure treatment, (2) exhaust air treatment, and (3) animal diet.

Manure additives are products generally reducing NH_3 volatilization from manure. Some of these are digestive (e. g. select microorganisms, enzymes) or NH_3 absorbing additives (McCrory and Hobbs, 2001; Li et al., 2008c). Another treatment is manure acidification through the use of sodium bisulfate or aluminum sulfate (Herber et al., 1999; Li et al., 2008c). At a pH of approximate 4.5 or lower, virtually all nitrogen present exists as nonvolatile ammonium (NH_4^+).

A strategy to reduce emissions from exhaust air is biofiltration, where a filter bed is established at the exhaust with a diverse population of aerobic microorganisms, which oxidize the reduced compounds generated by indoor confinement to CO_2, water, salts, and biomass (Leson and Winer 1991). Gas absorption is also a strategy to reduce emissions at the exhaust. Air is collected and passed through an enclosed tower with the absorption media (typically water) flowing counter-current to the air stream. Gases are diffused into and absorbed by the media (National Academy of Science, 2003). Another strategy to treat exhaust air is bioscrubbing, which has a similar concept to that of biofiltration, with the exception that the microorganisms are housed in an enclosed packed tower instead of in a filter bed (Lais, et al., 1997).

There have been several studies that quantified NH_3 emission reductions from diet manipulation. In general the studies are geared towards three objectives: (1) improving the nutrient utilization, thus reducing nitrogen and sulfur excreted; (2) additives to bind NH_3; and (3) additives to lower manure pH.

Natural zeolite [$(Na_4K_4)(Al_8Si_{40})O_{96}\cdot 24H_2O$] is a compound that could be used to reduce gaseous emissions in AFOs described above. It has useful ion-exchange and adsorption properties for filter material, diet supplement and/or manure additive to reduce NH_3 emission (Mumpton and Fishman, 1977). Li et al. (2008c), found that in topical application of zeolite NH_3 emissions decreased with increased application rate of the additive. Table 1 summarizes some of the uses of zeolite for NH_3 gaseous emission mitigation and corresponding results. Additionally, zeolite has been used as a filtration agent in deep bed anaerobic cattle manure (Milán et al., 1999). The DFC system, described in Chapter 3, included zeolite filters to achieve a relatively NH_3 free air supply. On-site filter efficiency is summarized in Chapter 3.

Table 1. Previous research summary on NH_3 emission reduction as a result of zeolite use.

Emission Source	Method	Zeolite Amount	Reduction	Reference
pig slurry	Combination of adding an easily degradable straw to the slurry and covering the composting material with zeolite minerals	*53 g kg^{-1}* of fresh chopped straw-pig slurry miture	80% of N-losses	Bernal et al., 1992
poultry manure	A layer of a zeolite containing mixture was placed on the surface of the manure	*60%* zeolite (weight basis)	44% of NH_3 emissions	Kithome and Paul, 1999
poultry manure	Topical application of zeolite on nearly fresh laying hen manure	up to *12.5 kg/m^2* of zeolite	up to 67% (±12%) of odors	Cai et al., 2006
poultry manure	Topical application of zeolite on nearly fresh laying hen manure	up to *12.5 kg/m^2* of zeolite	up to 77% NH_3 emissions	Li et al., 2008

Layer-hen diets

Dietary treatments, such as lowering the protein content, including high-fiber ingredients, or including EcoCal^{TM} (mixture of calciu sulfate and zeolite) have been shown to lower NH_3 emission (Liang et al., 2005; Roberts et al., 2007; Wu-Haan et al., 2007; Li et al., 2008b, Roberts et al., 2009). Amino acids supplied above the level of the limiting amino acid cannot be used and the nitrogen is excreted. A reduced protein content of the diet that more closely resembles the amino acid requirement of the animal, limits the amount of excess nitrogen that must be excreted. This is typically achieved through a reduced crude protein, and inclusion of crystalline amino acids (Liang et al., 2005). It was hypothesized by Roberts et al. (2009) that the inclusion of high-fiber ingredients (such as DDGS, wheat middlings and soy bean hulls) would provide energy to bacteria in the lower gastrointestinal tract where the bacteria use nitrogen, that would otherwise be excreted as uric acid, for bacterial protein synthesis; and the bacterial metabolism produces short-chain fatty acids that lower pH, thus shifting NH_3 to the less volatile NH_4^+. EcoCal is a mixture of calcium sulfate (i.e., gypsum) and zeolite. Calcium sulfate is an acidifier, replacing the dietary calcium carbonate (i.e. limestone), and zeolite binds ammonium in the manure. The reduced pH and binding of NH_4^+ result in reduced NH_3 emissions. The thesis research outlined in Chapter 3 focused on emission results from three diets, DDGS, EcoCal, and control. Table 2 summarizes results from some of the literature on DDGS and EcoCal treatment effects on NH_3 emissions.

Table 2. Previous research summary on NH_3 emission reduction as a result of DDGS and EcoCal use in layer-hen diets.

Emission Source	Diet Treatment	Amount of Total Weight	NH_3 Reduction Rate	Reference
laying-hens (lab scale)	DDGS	10%	50%	Roberts et al., 2007
laying-hens (lab scale)	EcoCal	6.9% EcoCal & 0.25, 0.18 & 0.20% Crude Protein	27, 44 & 46 %	Wu-Haan et al., 2007
laying-hens (lab scale)	DDGS	10%	17%	Hale, 2008
layng-hens (farm scale)	EcoCal	7%	63%	Lim et al., 2008
layng-hens (farm scale)	EcoCal	3.75%	23%	Li et al., 2008b
layng-hens (farm scale)	DDGS	10%	14%	Li et al., 2010
layng-hens (farm scale)	EcoCal	3.75%	7%	Li et al., 2010

Laying-hen high-rise barns

Emission measurements using both the MAEMU and the DFC were conducted in three high-rise hen houses in central Iowa. These houses were two story buildings, containing stair-step cage systems in the upper story with manure collected and stored in the lower story of the building. Ventilation fans were located on the sidewalls of the manure collection and storage area with air passing down through the cages and over the accumulated manure to remove gases and moisture evaporating from the manure (EPA, 2001). Eggs were collected on belts and transported to packaging stations. Feed was stored in grain bins and made available to the chickens through the use of augers.

After defecation manure was collected on dropping board areas located directly under each cage, which were scraped multiple times per day. Manure then fell into the lower story of the building, and over time manure accumulated to form piles across the length of the barn. Manure from the lower story was usually removed once per year and used as fertilizer through cropland application. A detailed description of the site is noted in Chapter 3.

Dynamic flux chambers (DFC)

A few reported field studies using enclosed chambers to measure emissions were done since the 1950s and 60s (Volk, 1959; Kresge and Satchell, 1960) with the principle of measuring NH_3 volatilization from varying surfaces. Subsequently, EPA made recommendations for the design and operation of a DFC (Kienbusch, 1986) where the chamber acts as a continuously stirred batch tank reactor (CSTR). Nevertheless, common applications of this design used flow rates as low as 5 $L \cdot min^{-1}$ or 4.6 ACH, which would likely result in fairly static air inside the chamber.

Since then, many studies have been conducted to improve flux chamber designs in order to achieve more representative gas emissions and better sample quality. For instance, the addition of instruments and computerization was done to allow automated and continuous sampling of multiple parameters such as gasses, temperature, pressure and flow rate (Boriack et al., 2005). Also, Rhoades et al. (2005) manufactured a flux chamber with a larger foot print in order to get a better representation of the emitting surface and reduce the number of samples needed. Moreover, Wheeler et al. (2007) constructed a flux chamber with the provision of a relatively uniform, horizontal air flow over the enclosed surface that was comparable to air velocity conditions measured outside the flux chamber. This resulted in a 26% underestimation of NH_3 emissions from an NH_3 balance method in a laboratory scale. However, Kissel et al. (1977) was among the first to observe fairly large variation in NH_3 emissions from lab scale and field measurements from what seemed similar conditions using a flux chamber (with air scrubbing to determine emissions).

Compared with the MAEMU, the DFC has the advantage of being portable, small size, low cost and less labor requirement. However, the DFC only covers a small area for each test which could overestimate or underestimate the emissions for large areas with non-homogeneous properties. In addition, the DFC artificially restricts air exchange between the manure surface and the outside air, which may be attenuated with short closure times (Messinger et al., 2001). Furthermore, the performance of DFC and thus the measured emission values may be subject to the influence of the system design and operational characteristics.

One such characteristic is the air flow rate through the system, which could affect the NH_3 mass transfer coefficient and NH_3 ER. Studies have shown seasonal variation in NH_3 concentrations in mechanically ventilated AFOs from the Northern Great Plains area in the United States, but have reported that ventilation rates occurring in the animal buildings seem to compensate for the variation and result in a fairly constant NH_3 emission rate (Liang et al., 2005). Jacobson et al. (2005) found that for four swine (finishing, gestation, and farrowing production stages) sites and two poultry (a layer and a broiler) sites NH_3 emissions were fairly constant though out the year. Also, Li et al. (2008b) observed no variation in NH_3 emissions for laying hens in high-rise houses among winter and spring months. However, Li et al. (2008a) found that NH_3 emission rate increased gradually for a Tom turkey barn throughout the spring-summer flock and then declined for the fall-winter flocks.

In the case of flux chambers it has been noted that flux measurements from urea in the soil are affected by air exchange rate (Kissel et al., 1977; Whitehead and Raistrick, 1991; Rhoades et al., 2005). Rhoades et al. (2005) observed that NH_3 fluxes measured on recent urine deposits increased up to 10-fold between air flow rates of 0.1 and 1.0 air exchanges per minute. In addition, several other studies have shown improvement in NH_3 emission estimation from wind tunnel and flux methods by matching air velocities over the emission source area to actual conditions (Ryden and Lockyer, 1984; Blanes Vidal et al., 2006; Wheeler et al., 2007). Ni (1999) concluded that NH_3 release is very closely related to the air velocity on manure surface; and Messinger et al. (2001) found that an increase in air velocity over the soil surface from 0.5 to 1.0 $m \cdot s^{-1}$ resulted in a 50% NH_3 emission increment.

In summary measuring emissions with flux chambers is restricted by the small footprint and the environment created inside the chamber. In essence, the chamber isolates the emitting surface from its natural environment, which may result in a bias measurement. Therefore, flux chambers measure the potential for a surface to emit a certain pollutant under the conditions inside the chamber, rather than actual emission. However, by determining what factors affect emissions inside a flux chamber we may get a better understanding of the actual emissions.

References

Bernal, M. P., J. M. Lopez-Real, and K. M. Scott. 1993. Application of natural zeolite for the reduction of ammonia emissions during the composting of organic wastes in a laboratory composting simulator. *Bioresource Technology*. 43:35–39.

Blanes Vidal, V., P. A. Topper and E. F. Wheeler. 2007. Validation of ammonia emissions from dairy cow manure estimated with a non-steady state, recirculation flux chamber with whole-building emissions. *Trans. ASABE.* 50(2): 633-640.

Boriak C., R. E. Lacey, S. Mukhtar, A. Mutlu, S. C. Capareda, B. W. Shaw and C. B. Parnell. 2004. A Multiplexer System for Measurement of Gaseous Emissions. ASABE paper No. 044183. St. Joseph, Mich.: ASABE.

Broder, J. M. 2009. E.P.A. expected to regulate carbon dioxide. The New York Times. Available at: NYTimes.com. Accessed 24 June 2010.

Cai, L., J. A. Koziel, Y. Liang, A. T. Nguyen, and H. Xin. 2007. Evaluation of zeolite for control of odorants emissions from simulated poultry manure storage. *Environmental Quality*. 36:184-193.

CFR. 2005. Concentrated animal feeding operations. Code of Federal Regulations – Title 40: Protection of Environment. Available at: http://cfr.vlex.com/vid/. Accessed 21 May 2010.

EPA 2001. Emissions from animal feeding operations. EPA Contract No. 68-D6-0011. Research Triangle Park, NC.: U.S. Environmental Protection Agency.

Ferguson, R. B., K. J. McInnes, D. E. Kissel, and E. T. Kanemasu. 1988. A comparison of methods of estimating ammonia volatilization in the field. *Fertilizer Research*. 15: 55-69.

Fraser, D., 2005. *Animal welfare and the intensification of animal production: An alternative interpretation*. Rome, Italy: Editorial Production and Design Group Publishing Management Service FAO.

Heber, A., D. Jones, and A. Sutton. 1999. Methods and practices to reduce odor from swine facilities. Purdue University Cooperative Extension Service. West Lafayette, Indiana.

Jacobson, L. D., J. R. Bicudo, D. R. Schmidt, S. Wood-Gay, R. S. Gates and S. J. Hoff. Air emissions from animal production facilities. ISAH 2003, Mexico.

Jacobson, L. D., B. P. Hetchler, V. J. Johnson, R. E. Nicolai and D. R. Schmidt. 2005. Seasonal variations in NH_3 and PM_{10} emissions from pig and poultry buildings from a multi-state project. In Proc. *Symposium on the State of the Science of Animal Manure and Waste Management.* San Antonio, Texas: ASABE.

Kienbusch, M. R., 1986. USEPA Measurement of gaseous emission rates from land surfaces using an isolation flux chamber, user's guide. EPA Contract No. 60-02-3889. Radian Corporation, EPA/600/8-86/008.

Kinbush, M. (1985), *Measurement of gaseous emissions rates from land surfaces using an emission isolation flux chamber: User's Guide*, EPA User's Guide, Contract No. 68-02-03389-WA18.

Kissel, D. E., H.L. Brewer, and G. F.Arkin. 1977. Design and test of a field sampler for ammonia volatilization. *Soil Sciencee of America*. 41:1133-1138

Kithome, M., J. W. Paul, and A. A. Bomke. 1999. Reducing nitrogen losses during simulated composting of poultry manure using adsorbents or chemical amendments. *Environmental Quality*. 28:194–201.

Koziel, J. A., D. B. Parker, B. H. Baek, K.J. Bush, M. Rhoades and Z. Pershbacher-Buser. 2005.Ammonia and hydrogen sulfide flux from beef cattle pens: Implications for air quality measurement methodologies and evaluation of emission eontrols. In Proc. *7th International Symposium*. Paper No.701P0205. Beijing, China: ASABE.

Kresge C. B., and D. P. Satchell. 1960. Gaseous loss of ammonia from nitrogen fertilizers applied to soils. *Agronomy*. 52:104-107

Lais, S., E. Hartung, and T. Jungbluth. 1997. Reduction of ammonia and odour emissions by bioscrubbers. Voermans JAM, Monteny G, editors. In Proc. *International Symposium on Ammonia and Odour Control from Animal Production Facilities.*, 2: 533-536. Rosmalen, The Netherlands.

Leson, G. and A.M. Winer. 1991. Biofiltration: An innovative air pollution control technology for VOC emissions. *Air and Waste Management Association*. 41(8):1045-54.

Liang, Y., H. Xin, E. F. Wheeler, R. S. Gates, J. S. Zajaczkowski, P. Topper, H. Li, and K. D. Casey. 2005. Ammonia emissions from U.S. laying hen houses in Iowa and Pennsylvania. *Trans. ASAE* 48(5): 1927-1941.

Liu, Z., L. Wang and D.B. Beasley. 2008. Comparison of three techniques for determining ammonia emission fluxes from broiler litter. *Trans. ASAE.* Vol. 51(5): 1783-1790.

Li H., H. Xin, R. T. Burns, S. J. Hoff, J. D Harmon, L. D. Harmon, L. D. Jacobson, S. Noll, J. A. Koziel. 2008a. Ammonia and PM emissions from a tom turkey barn in Iowa. ASABE paper No. 084425. St. Joseph, Mich.: ASABE.

Li, H., H. Xin, R. T. Burns, S. A. Roberts, and K. Bregendahl. 2008b. Effects of dietary modification on laying hens in high rise houses: Part I – emission of ammonia, hydrogen sulfide and carbon dioxide. ASABE paper No. 701P0408. St. Joseph, Mich.: ASABE.

Li, H., H. Xin, Y. Liang, and R. T. Burns, 2008c. Reduction of ammonia emissions from stored laying hen manure through topical application of Zeolite, Al^+ Clear, Ferix-3, or Poultry Litter Treatment. *Applied Poultry Research*. 17(4): 421 – 431.

Li. H. and H. Xin. 2010. Emissions of ammonia, hydrogen sulfide and greenhouse gases from laying hens in commercial high-rise houses affected by dietary modification. ASABE. St. Joseph, Mich.: ASABE.

McCrory, D.F. and P.J. Hobbs. 2001. Additives to reduce ammonia and odor emissions from livestock wastes: A review. *Environmental Quality*. 30:345-355.

Messinger, J. J., A. M. Lefcourt, and R. B. Thompson. 2001. Construction and validation of small mobile wind tunnels for studying ammonia volatilization. *Applied Engineering in Agriculture.* 17(3): 375-381.

Milan, Z., E. Sanchez, R. Borja, K. Ilangovan, A Pellon, N. Rovirosa, P. Weiland, and R. Escobedo. 1999. Deep bed filtration of anaerobic cattle manure effluents with natural zeolite. *Environmental Science and Health*. B 34:305–332.

Mumpton, F. A., and P. H. Fishman. 1977. The application of natural zeolites in animal science and aquaculture. *Animal Science*. 45:1188–1203.

National Academy of Science. 2003. *Air emissions from animal feeding operations current knowledge, future needs.* Washington D.C.: The National Academy Press.

Ni, J. (1999). Mechanistc Models of ammonia release from liquid manure: A review. *Agricultural Engineering Research*. 72: 1 – 17.

Rhoades, M. B., D. B. Parker, B. Auvermann, N. A. Cole, Z. Perscbancher-Buser, and R. E. DeOtte. 2005a. Factors affecting emissions measurements with surface isolation flux chambers. ASAE paper No. 054026. St. Joseph, Mich.: ASABE.

Rhoades, M. B., D. B. Parker and Z.L. Perschbacher-Buser. 2005b. Design and Construction of a Large Surface Isolation Flux Chamber for Ammonia Emission Measurements. ASAE paper No. 054071. St. Joseph, Mich.: ASABE.

Roberts, S.A., H. Xin, B.J. Kerr, J.R. Russell, and K. Bregendahl. 2007. Effects of dietary fiber and reduced crude protein on ammonia emission from laying-hen manure. *Poultry Science*. 86:1625–1632.

Roberts, S. A., H. Xin, H. Li, R. T. Burns, K. Bregendahl, and E.C. Hale. 2009. Dietary manipulations to lower ammonia emission from laying-hen manure. In Proc. *Mitigating Air Emissions from Animal Feeding Operations Conference*. Ames, Iowa: ISU.

Ryden, J. C., and D. R. Lockyer. 1984. Evaluation of a system of wind tunnels for field studies of ammonia loss from grassland through volatilization. *Science of Food and Agriculture.* 36(9): 781-788.

Volk, G. M. 1959. Volatile loss of ammonia following surface application of urea to turf or bare soils. *Agronomy*. 51:746-749.

Wheeler E. F., P. A. Topper, and T. L. Richard. 2007. Validation of flux chamber technique for estimate gaseous emission in situ from naturally-ventilated facilities. In *Proc. International Symposium on Air Quality and Waste Management for Agriculture Conf.,* 701P0907cd.

Whitehead D. C., and N. Raistrick. 1991. Effect of some environmental factors on ammonia volatilization from simulated livestock urine applied to soil. *Biology and Fertility of Soils* 11:279-284.

Wu-Haan, W., W. J. Powers, C. R. Angel, C. E. Hale III, and T. J. Applegate. 2007. Effect of an acidifying diet combined with zeolite and slight protein reduction on air emissions from laying hens of different ages. *Poultry Science.* 86: 182–190.

Chapter 2: Effects of Air Flow Rate and Inlet Angle of a Dynamic Flux Chamber on Measurement of NH_3 and CO_2 Emissions from Laying-Hen Manure

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Abstract

The high costs of sophisticated air quality monitoring systems such as mobile air emissions monitoring unit limit their use for air emissions measurement and mitigation studies. In some cases such as naturally-ventilated animal or manure storage barns, air exchange rate of the emitting source is formidable to determine. Consequently, a need for alternative methods to dependably quantify air emissions arises. Several methods, such as gas-washing, micro-meteorological, wind tunnel, flux chamber and mass-balance methods have been employed to accommodate different measurement needs. Flux chambers have the advantages of being portable, small size, low cost, and less labor requirement. However, the performance of flux chambers and thus the measured emission values may be subject to the influence of the system design and operational characteristics. The objective of this study was to assess the impact of operational parameters on the performance of a dynamic emission flux chamber (DFC), including: (1) air exchange rate expressed in air changes per hour (20, 39, 58 and 78 ACH), and (2) air turbulence or velocity over the manure surface resulting from different air inlet angles (0 *vs.* 45 degree from the horizontal plane) into the DFC space.

Results of laboratory tests with laying-hen manure revealed that measured NH_3 and CO_2 emissions are positively related to DFC ACH. Both NH_3 and CO_2 emissions increased with ACH, however CO_2 appeared to be approaching a maximum emission at higher ACH, while NH_3 emissions increased linearly with ACH. Higher air velocities (0.07 *vs.* 0 $m \cdot s^{-1}$ at 39 ACH) over the manure surface as a result of the different air inlet angles (0 *vs.* 45 degrees) were shown to positively affect the measured gaseous emissions.

Keywords. Ammonia emission, flux chamber, mobile air emissions monitoring unit, emission mitigation

Introduction

Air emissions from animal feeding operations (AFOs) can include ammonia (NH_3), nitrous oxide (N_2O), hydrogen sulfide (H_2S), carbon dioxide (CO_2), methane (CH_4), total reduced sulfur compounds (TRS), volatile organic compounds (VOC), and particulate matter (including total suspended particle or TSP, PM_{10} and $PM_{2.5}$). Gaseous emissions are affected by environmental conditions, ventilation rate, dietary composition, animal activities, animal life stage, manure properties (e.g. moisture content, pH), and manure management practices (Liang et al., 2005).

The issue that most often brings air emissions to the attention of public officials is the frequency of complaints about objectionable odors voiced by neighbors of AFOs. Emissions may trouble residents because of actual or perceived health effects. Additionally, various substances in air emissions contribute to environmental degradation, such as eutrophication of water bodies or climate change (National Academy of Science, 2003).

NH_3 is mainly produced by the decomposition of nitrogenous compounds in manure through the inefficient conversion of feed nitrogen to animal products. Its characteristic strong odor makes it easily detectable at 5 to 10 ppm. CO_2, on the other hand, is odorless and produced mainly by animal respiration and secondary by manure decomposition. The generation of both gases from poultry facilities occurs through the degradation of uric acid in the manure, although CO_2 is primarily from animal respiration (Pedersen et al., 2008). NH_3 can contribute to fine particulate formation ($PM_{2.5}$) and when deposited back to the earth contributes to nutrient over-enrichment in aquatic systems and acidification of the environment, while CO_2 is considered to be a greenhouse gas contributing to climate change (EPA 2001).

In 2001 the U.S. Environmental Protection Agency (EPA) released a report on “Emissions from Animal Feeding Operations” that assessed the value of available information to support future air pollution policy decisions regarding AFOs. The report recognized various data gaps to develop a complete set of emission estimates for model farms. To do so and investigate efficacy of emissions mitigation strategies, practical and dependable methods to quantify air emissions are needed.

Mobile air emissions monitoring units (MAEMUs) are capable of precise and real-time emission measurement and are typically used for continuous, intensive monitoring of emissions from mechanically ventilated animal facilities. However, their relative immobility and high costs limit the widespread use for baseline emission or mitigation studies. Several other methods, such as gas-washing, micro-meteorological, wind tunnel, flux chamber, and mass-balance methods have been employed to accommodate different measurement needs (Koziel et al., 2005; Liu et al., 2008). Flux chambers have the advantages of being portable, small size, low cost, and less labor requirement. However, the performance of flux chambers and thus the measured emission values may be subject to the influence of the system design and operational characteristics.

Kienbusch (1986) developed a flux chamber "user's guide," which detailed the flux chambers physical appearance and function, however standards for the operational parameters are lacking. Several studies have been conducted on the use, efficacy and operation of flux chambers. Of particular interest for this study are the effect fresh air flow rates through the chamber, and air velocity over the emission source surface. It has been documented that flux measured from urea in the soil are affected by air exchange rate (Kissel et al., 1977; Whitehead and Raistrick, 1991; Rhoades et al., 2005). Rhoades et al. (2005) observed that NH_3 fluxes measured on recent urine deposits increased up to 10-fold between airflow rates of 0.1 and 1.0 air exchanges per minute, which is within normal ventilation rates for laying-hen houses in the Midwest. In addition, several other studies have shown improvement in NH_3 emission estimation from wind tunnel and flux methods by matching air velocities over the emission source area to actual conditions (Ryden and Lockyer, 1984; Blanes Vidal et al., 2006; Wheeler et al., 2007). Hoff et al. (1981) was amongst the first to observe the underestimation of NH_3 loss on windy days from swine manure applied to cropland using a flux chamber. Later on, Ni (1999) concluded that NH_3 release is very closely related to air velocity at manure surface; and Messinger et al. (2001) found that an increase in air velocity over the soil surface from 0.5 to 1.0 $m \cdot s^{-1}$ resulted in a 50% NH_3 emission increase with no air recirculation inside the vessel. The combined effect of both parameters seem to be absent in the literature.

The objective of this study was to assess the impact of operational parameters on the performance of a dynamic emission flux chamber (DFC), including: (1) air exchange rate expressed in air changes per hour (20, 39, 58, or 78 ACH), and (2) air turbulence or velocity over the manure surface resulting from different air inlet angles (0 *vs.* 45 degrees from the horizontal plane) into the DFC space.

Materials and Methods

Dynamic Flux Chamber System

This research was conducted *in the Livestock Environment and Animal Physiology (LEAP) Laboratory II at* Iowa State University. The DFC was made of a 0.32 m diameter nearly semi-spherical vessel constructed of stainless steel, with a 12.3 L volume (fig. 1). It had an internal sample port, a fitting to check pressure and an adjustable exhaust valve located at the top of the vessel. The DFC also had four air inlet ports that split from one distribution line, equally spaced along the perimeter of the vessel. The air inlets were positioned to form a race-track airflow pattern, thereby facilitating good air mixing inside the DFC without use of an auxiliary mixing fan.

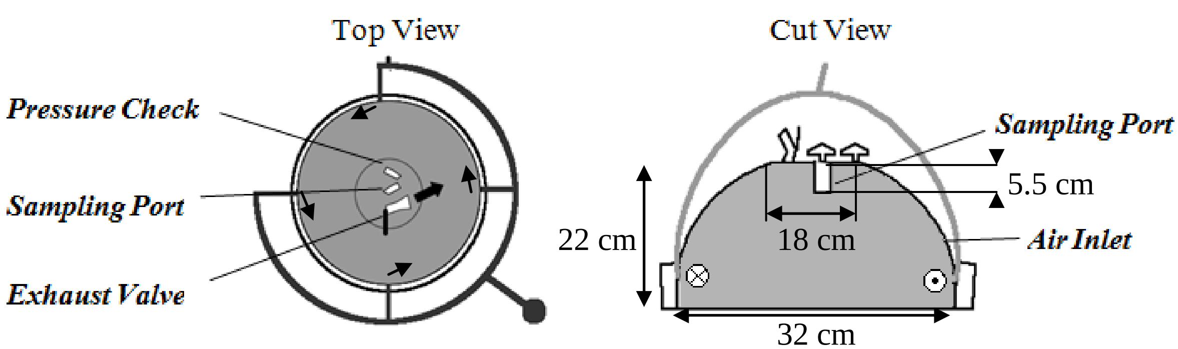

Figure 1. Schematic representation of the dynamic flux chamber system (DFC).

Fresh air to the chamber was supplied using a pump (model 2688CE44-010, Rupprecht & Patashnick Co. Inc., located in East Greenbush, NY) with a capacity of 50 L·min^{-1}, or two Gast DDL linear air pump (Gast Manufacturing, Benton Harbor, MI) with a capacity of 10 $L \cdot min^{-1}$. The flow rate controlled using a flow meter (model VFB-67-SSV, Dwyer Instruments, Michigan City, IN 0 to 20 $L \cdot min^{-1}$ range). Pressure inside the chamber was measured with a manometer (Dwyer, model 25, MARK II) with a -0.05 to 3 in-H_2O range. For all measurements the pressure was near 0 in-H_2O regardless of the air flow rate.

The DFC had an outer replaceable ring made of 0.404 mm galvanized metal. Silicon glue was used around the chamber to seal the contact with the ring. The ring penetrates the manure by approximately 5 cm to avoid or minimize leakage through the bottom of the DFC and force the air to pass through the designated sampling and exhaust ports at the top.

For the purpose of this evaluation study, a photoacoustic mutilple-gas analyzer (INNOVA 1412, AirTech Instruments A/S, Ballerup, Denmark) was used to measure NH_3 and CO_2 concentrations, with detection limits of 0.2 and 12.5 ppm, respectively. The INNOVA's own (internal) pump was used to extract the air from the chamber to be sampled approximately every 30 s. Air passed through 4 mm OD x 3 mm ID Teflon tubing (Applied Plastics Technology Inc., Bristol, RI) from the sampling port to the INNOVA, while a more flexible, clear 9.525 mm OD x 6.35 mm ID Tygon tubing (Saint Gobain Performance Plastics Inc., Beaverton, MI) was used for all other purposes.

Experiment Considerations Based on Preliminary Trials

A set of preliminary trials were conducted to observe the temporal changes in gaseous emissions from hen manure and the effect of varying air changes on gaseous emissions. An experiment design was developed that tested air flow rates of 10, 20, 29 and 39 ACH using the DFC. The purpose of the preliminary trials was to determine which variables could be discarded or manipulated, and to direct the scope and thus design of the subsequent main experiment.

This study was conducted using an environment-controlled system in a laboratory at Iowa State University. Manure was obtained from laying hen chickens, each batch corresponding to a different age group. The chickens were caged and the manure accumulated in a plastic sheet below. A random selection of the manure was placed in buckets and placed in a cold room to conserve manure properties. Manure was placed and well mixed inside a 261 L (69 gallon) clear plastic box, so that the complete area under the DFC would have manure at a depth of approximately 3 cm. At least 5 hours were allowed prior to use for temperature to normalize.

Table 1. Observations obtained during pretrials which resulted in guidelines to be followed in the subsequent experiment

Preliminary Trial Observation	Resulting Guideline
It was found that for an average duration of 6.5 hr there was no convincing evidence that indicated gaseous emission of NH_3 and CO_2 varied over time for a particular flow rate for 3 out of the 5 trials.	A fully randomized application of ACH was done for each trial, since no evidence of a decrease in gaseous emissions among repetitions was observed for average trial duration of 6.5 hours.
A trend of increasing emissions with repetition was observed for the other 2 trials, which seemingly contradicts Edeogu et al. (2001) and Li (2006), who stated that manure odor emissions decreased with time. It was also observed that concentrations stabilized after some time (fig. 2). This suggests that manure temperature had not reached equilibrium (Pratt et al., 2002); possibly because the sample temperature was not able to normalize after it was placed in the container for measurements.	A minimum of 20 hours was set for manure temperature to normalize prior to sampling.
In addition, the increases in gas concentrations were subtle and did not result in a significant coefficient of variance (CV) for a 5 minute period. The change was hard to detect when using the INNOVA for "stand alone" measurements.	A computer was used to graph "real time" gas concentrations measured with the INNOVA 1412.

Moreover, there was convincing evidence that a difference existed in NH_3 emissions among ACH, as the least squared mean of the log transformed emissions increased with ACH (table 2).	Increased NH_3 and CO_2 emissions were observed with increased ACH, thus, the effect ACH on emissions was studied further.
Furthermore, it appeared that manure properties varied substantially from batches to batch with a direct effect on manure emissions. Higher manure moisture content (Ave = 58% SE = 4.12% for n = 11) resulted in higher gas emissions, and higher percent of dust, feathers and feed in manure resulted in lower gas emissions.	A more consistent source of manure and collection was used, since manure properties varied substantially from batch to batch.
Finally, The increase in NH_3 and CO_2 emissions with ACH were best explained by a linear and quadratic model, respectively (fig. 3). Thus, the question of the existence of an emission maximum arises; both as a result of changes in velocity over the manure surface that causes a reduction in the interfacial boundary layer or other limiting factors such as moisture content.	A wider range of ACH was selected (20, 39, 58 and 78 ACH) in search of gaseous emission maximums for NH_3 and CO_2.

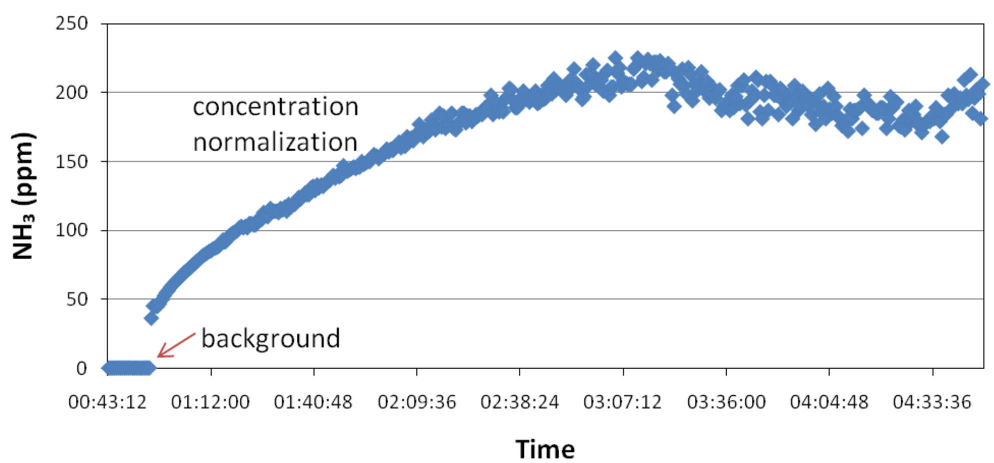

Figure 2. Snapshot of a trial, where NH_3 concentrations increased steadily with time.

Table 2. NH_3 and CO_2 log transformed emissions for preliminary trials for each air exchange rate. A total of 20 observations were used

ACH		10		20		29		39	
NH_3	ER	0.085		0.128		0.140		0.186	
	95% CI	0.063	0.115	0.095	0.174	0.104	0.190	0.137	0.251
CO_2	ER	7.74		8.17		8.76		11.94	
	95% CI	6.34	9.44	6.70	9.97	7.18	10.69	9.79	14.57

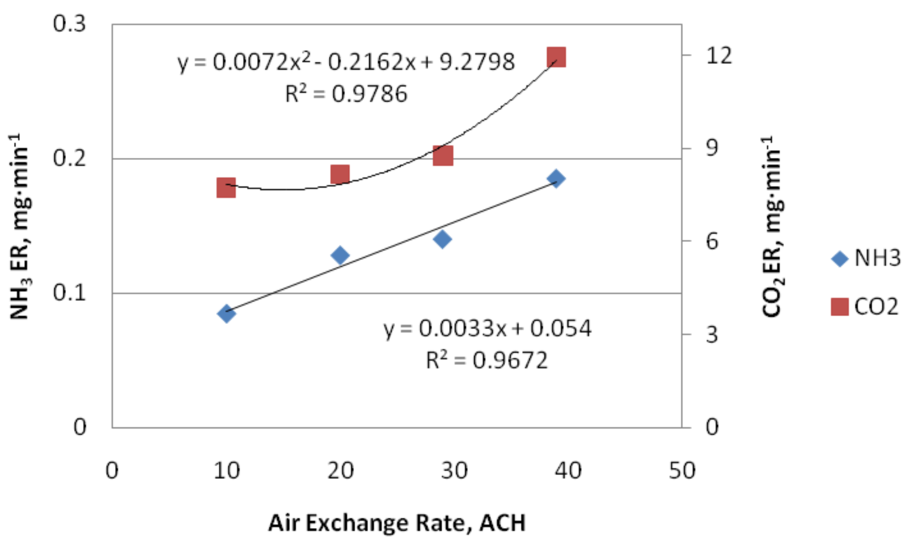

Figure 3. NH_3 and CO_2 emission rate (ER, mg·min^{-1}) at different air exchange rates. Standard errors of 0.54 and 0.35 were obtained for NH_3 and CO_2 log transformed emissions respectively. n = 20

Air Velocity Profile Measurement

The chamber was placed on top of a clear plexi-glass plastic with the exact boundary of the chamber. The plastic had 17 holes (diameter 6.35 mm) drilled on it (fig. 4) along four directions of 45 degrees from one another and the centers of the openings in each line were spaced equally. Approximately 2.54 cm (1 inch) long 6.35 mm ID Tygon tubing was inserted into and glued to each hole, and the plexi-glass was covered with soil to simulate manure surface. The purpose of the tubing was to prevent the velocity transducer to come in contact with the soil and prevent soil/air from escaping through the openings. All the openings were taped underneath the plexi-glass and a flow rate was applied through the chamber. One opening was uncovered at a time and the velocity at the hole was measured and recorded in $m \cdot s^{-1}$ with an omni-directional velocity transducer (0.001 $m \cdot s^{-1}$ detection limit; model 8475-12, TSI Davis Instruments, St. Paul, MN) for all flow rates. After all flow rates were applied and the velocities were recorded the transducer was moved 2.54 cm (1 inch) further inside the DFC and the data were recorded, until the transducer could not go further. Once the first hole was completed, it was covered with tape and the next hole was uncovered and the velocity measured, following the same procedure. This was done for all 17 holes, providing a total of 126 measurements for each flow rate.

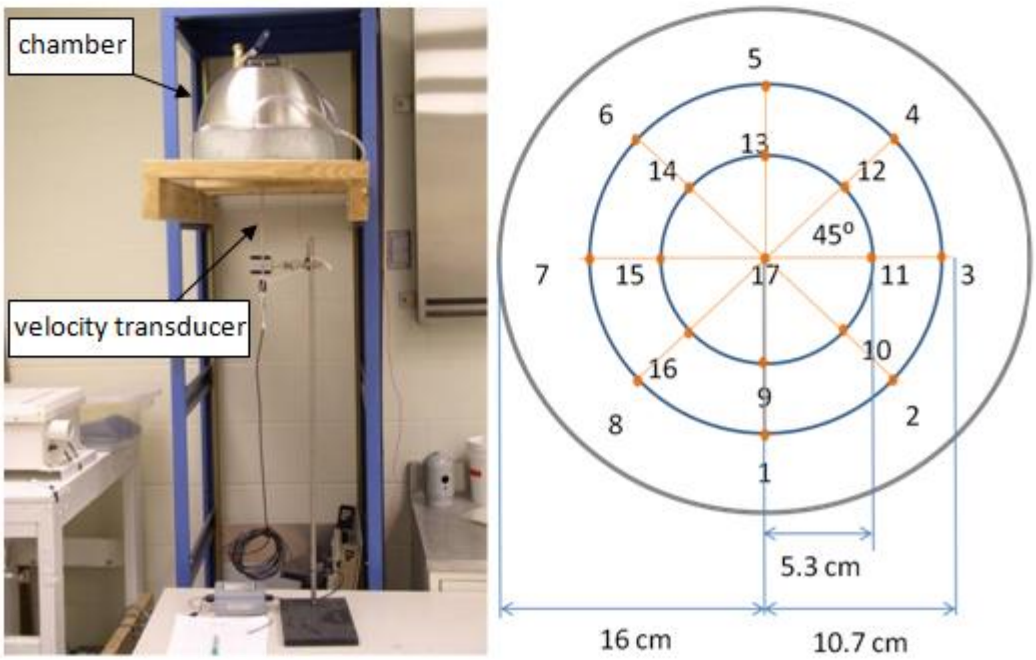

Figure 4. Experimental setup and schematic illustration for quantifying air velocity profile inside the dynamic flux chamber (DFC), air velocity transducer, and horizontal locations of the velocity measurement.

Experimental Design

Air flow rate and air inlet angle effects on air velocity

A comparison of air velocities inside the DFC among 10, 20, 29, 39, 58 and 78 ACH (2, 4, 6, 8, 12, and 16 $L \cdot min^{-1}$ flow rate) at an angle of 45 degrees with respect to the surface (air flowing in a clockwise racetrack pattern) was made. As shown in figure 4, for each ACH, air velocity was measured across the diameter of the DFC in four directions (45 degree apart). The number of velocity measurement points varied from 17 points for the bottom tier (2.54 cm above the covered surface) to 8 points for the top tier (20.3 cm form the covered surface, at equal vertical increments of 2.54 cm). This yielded a total of 126 air velocity measurements per ACH. The data were subject to a 3-way ANOVA using the “proc glm” function of SAS program.

A similar experiment was designed and conducted to achieve a comparison of air velocities inside the DFC as affected by two air inlet angles of 0 and 45 degrees into the DFC at air exchange rate of 39 or 78 ACH (8 or 16 $L \cdot min^{-1}$). Data collection followed the same procedure as described above. The data were subject to a 4-way ANOVA using the "proc glm" function of SAS program.

Air flow rate and velocity profile effects on emissions

A randomized experiment design was used to achieve comparisons of gaseous emissions among air flow rates of 20, 39, 58, 78 ACH (4, 8, 12, and 16 $L \cdot min^{-1}$), all at an inlet angle of 45 degrees relative to the surface. The air exchange rates fell within ventilation rates of laying-hen facility operations. Manure used in the evaluation study was from laying hens that were 24 to 32 weeks of age, fed a typical diet for the age range, and housed in cages. The collected manure was stored in a cold room to conserve manure properties. Approximately 6.12 kg or 6 L of manure was obtained for each batch. Prior to each test the manure was placed and well mixed inside a 261 L plastic box (fig. 5) and kept at room conditions for at least 20 hr to achieve stabilization. Average manure temperature was 22.5 (± 0.64 SE) °C as determined with a HOBO temperature sensor (Onset Computer, Pocassset, MA); and average moisture content (MC) was 74 (± 0.5) % "as-is" basis as determined by oven-drying method (Symons and Morey, 1941).

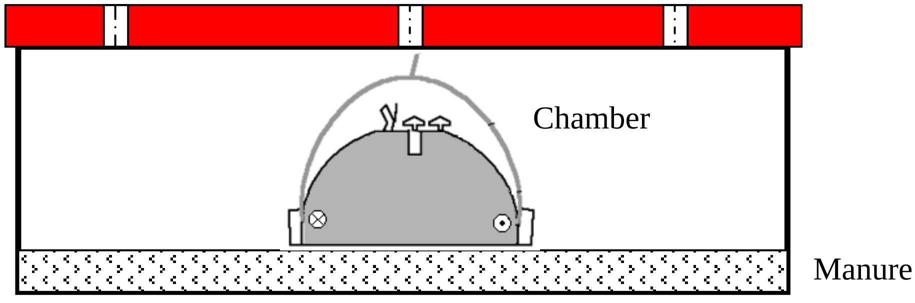

Figure 5. Sketch of DFC sampling in emission rate comparison

The INNOVA gas analyzer was allowed to warm up for 20 min prior to test measurement. Then background concentrations were determined by drawing the air directly from the air inlet to the analyzer. These concentrations (C_o) were used in the emission calculations. The container was placed inside the lab's fume hood to reduce odors. The DFC was then placed at the middle of the manure-laden container (fig. 5). The exhaust valve was completely opened and the air inlets inside the chamber were set at 45 degrees. A lid with holes was used to cover the container. The lid helped block potential artifact effects from the fume hood on the DFC or drying the manure. The openings helped avert gas build-up inside the box. The DFC inlet, sampling port and pressure check tubing were run through one of the openings of the lid.

The air supply to the DFC system was provided from the room air inlet to ensure fresh air and minimize CO_2 concentration variations as a result of personnel presence. Air flow rates of 20, 39, 58 and 78 ACH were applied in a random order. Each ACH treatment was applied until at least 5 air exchanges occurred (approximately 16, 8, 6 and 4 min respectively) and coefficient of variation (CV = SD/mean x 100%) for the gas concentration readings was less than 5%. The final five concentration readings (last 2 min) for each ACH were averaged and used in the emission calculation. Each ACH was applied three times per batch of manure as described above. In total five batches of manure were used. Because of possible variation among batch properties, batches were considered a block. The results were analyzed by an ANOVA using the "proc glm" function of the SAS program. Figure 6 shows a flowchart representation of the described procedure.

Emission rate calculations was as follows:

$$ER = \frac{Q(C_e - C_i)W_m T_{std} P_a}{10^6 V_m T_a P_{std}} \times 10^3$$

(1)

where:

ER = emission rate, $mg \cdot min^{-1}$

Q = flow rate going into the chamber, $L \cdot min^{-1}$

C_e = gas concentration of air leaving the chamber, ppm

C_i = gas concentration entering the chamber, ppm

W_m = molecular weight of the gas, $g \cdot mol^{-1}$

V_M = molar volume at standard temperature (0° C) and pressure (101.325 kPa), 22.4 L mol^{-1}

T_{std} = standard temperature, 273.15 K

P_{std} = standard pressure, 101.325 kPa

P_a = local barometric pressure, 97 kPa

T_a = temperature of the sample air, 293.15 K

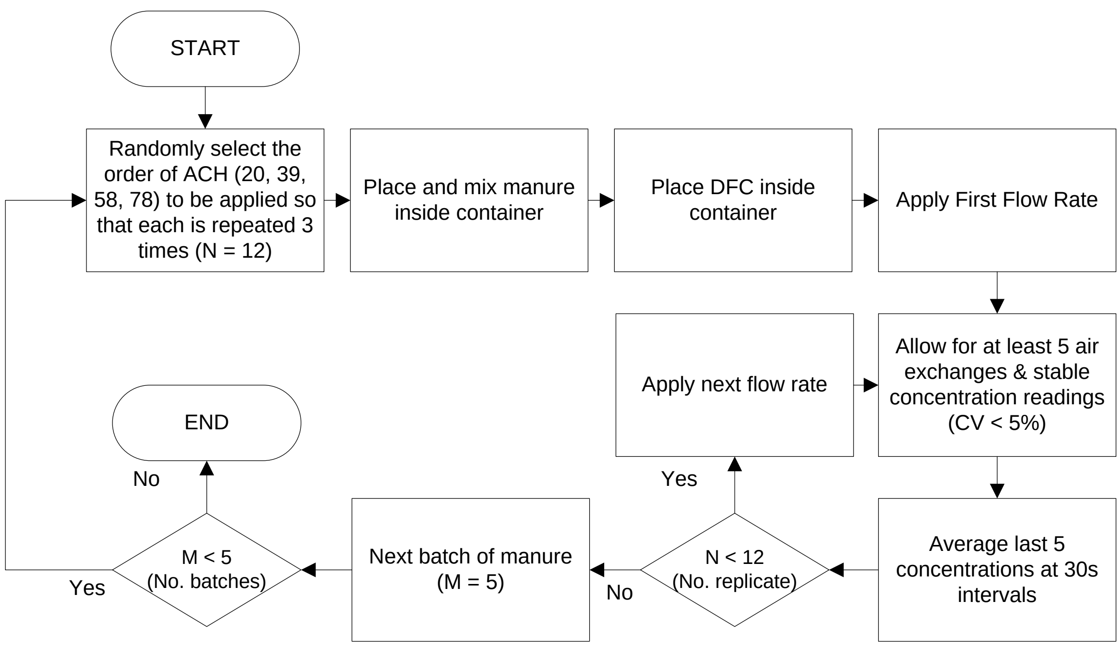

Figure 6. Flow chart representation of procedure for evaluating the effects of air exchange rates on NH_3 and CO_2 emissions

Air inlet orientation effect on emissions

A 2 x 2 factorial experiment design was used to assess the effects of air inlet orientation on gaseous emissions, including 39 and 78 ACH (8 and 16 $L \cdot min^{-1}$) by inlet angles of 0 and 45 degrees (with respect to the manure surface). A total of 5 trials were done, and all possible combinations (ACH and angle) were sampled 3 times for each trial and the average was calculated per combination. The procedure and setup were the same as described in the 'Air Exchange Effect' section with the exception that each treatment consisted of a flow rate (39 or 78 ACH) and inlet angle (0 or 45 degrees with respect to the manure surface). The data were analyzed by an ANOVA using the "prco glm" function of the SAS program. The significance (strong *vs.* weak evidence) of the obtained p-values was interpreted as indicated by Ramsey and Shafer (2002) for all analyses.

Results and Discussions

Effect of Air Flow Rate on Air Velocity Profile

There were significant differences in air velocities inside the DFC with varying ACH ($P < 0.0001$). In general, air velocities increased with increasing ACH, but at 10, 20 and 29 ACH the air was fairly static and no difference was observed, as shown in Figures 7 and 8. The highest velocities usually occurred in locations near the DFC wall. Also, in the case of 58 and 78 ACH there were higher velocities near the surface.

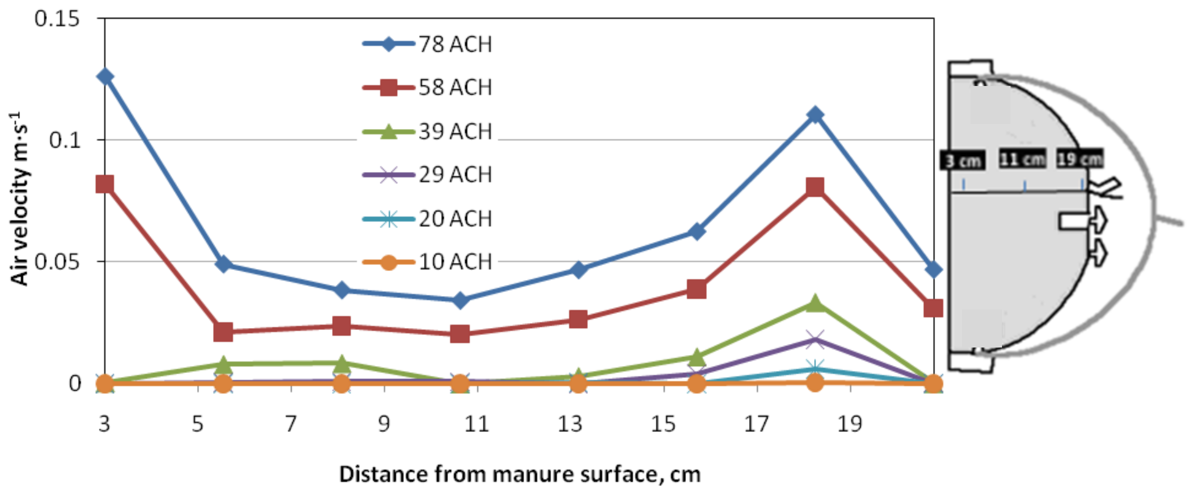

Figure 7. Air velocity profile inside the dynamic flux chamber (DFC) at different distances from the manure surface for 10, 20, 29, 39, 58 and 78 ACH, with an air inlet angle of 45 degrees. n = 17 for 2.54 to 12.7 cm; n = 16 at 15.24 cm; and n = 8 at 20.32 cm for each ACH.

Additionally, when looking at the horizontal cross-section there wass convincing evidence that the air velocities were different for 39 ACH through 78 ACH. The highest velocities were recorded at 10.7 cm from the center (fig. 8), near the DFC wall, where the air inlets were positioned. There was no difference between the center and 5.3 cm location.

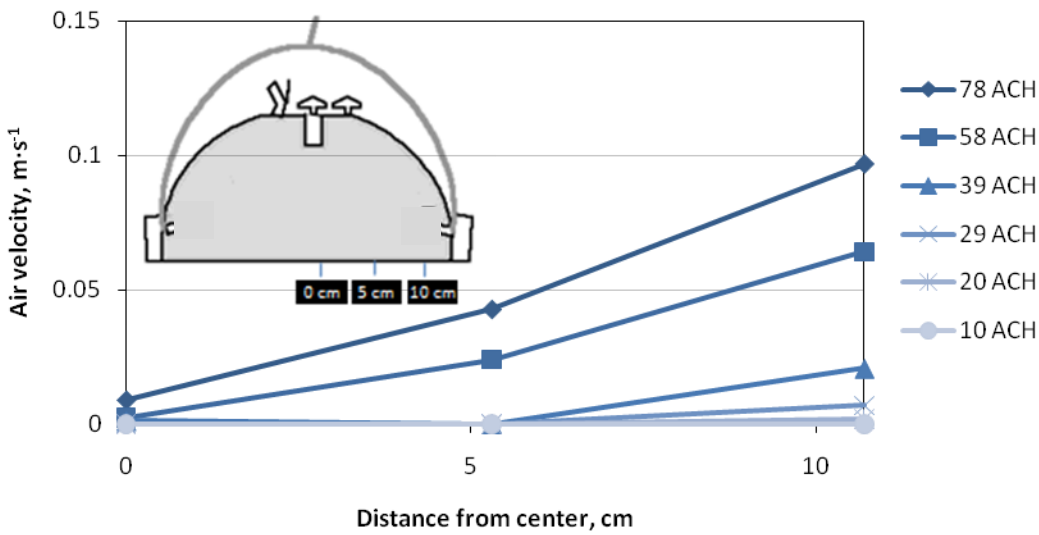

Figure 8. Air velocity profile inside the chamber at different distances from center, obtained from 10, 20, 29, 39, 58 and 78 ACH, with an air inlet angle of 45 degrees. n = 6 at 0 cm, n =64 at 5.3 cm, and n = 56 at 10.7 cm for each ACH

Table 3 lists the mean velocity under the DFC for each ACH. In summary, air under the DFC was fairly static for air flow rates up to 39 ACH. Velocities obtained from 58 and 78 ACH were significantly different from each other and from all the other ACHs ($p < 0.0001$). Also, in general velocities in the center area of the DFC were the lowest.

Table 3. Mean air velocity inside the dynamic flux chamber (DFC) space for different air changes per hour (ACH). n = 126 (SE = 0.003)

Air flow rate, ACH	10	20	29	39	58	78
Air velocity, $m \cdot s^{-1}$	0.000	0.001	0.003	0.009	0.041	0.065

Effect of Air Inlet Orientation on Air Velocity Profile

Air inlet orientation showed an effect in air velocity distribution inside the DFC if we divide the vertical cross section into zones as shown in figure 9, with 2.54 to 7.62 cm from the surface comprising the lower zone; 10.6 to 12.7 cm the middle zone; and 15.2 to 20.3 cm the upper zone. At an air inlet angle of 0 degrees air velocities in the lower zone were the highest; on the other hand, at an air inlet angle of 45 degrees the highest air velocities were in the upper zone. In addition, at an air inlet angle of 0 degrees there was a higher air velocity at 2.54 cm from the surface compared to all other locations in the vertical cross section ($p < 0.0001$). Also, though no significant difference was found among most of the locations on the vertical cross section at an air inlet angle of 45 degrees the highest average velocity was obtained at 17.8 cm from the surface.

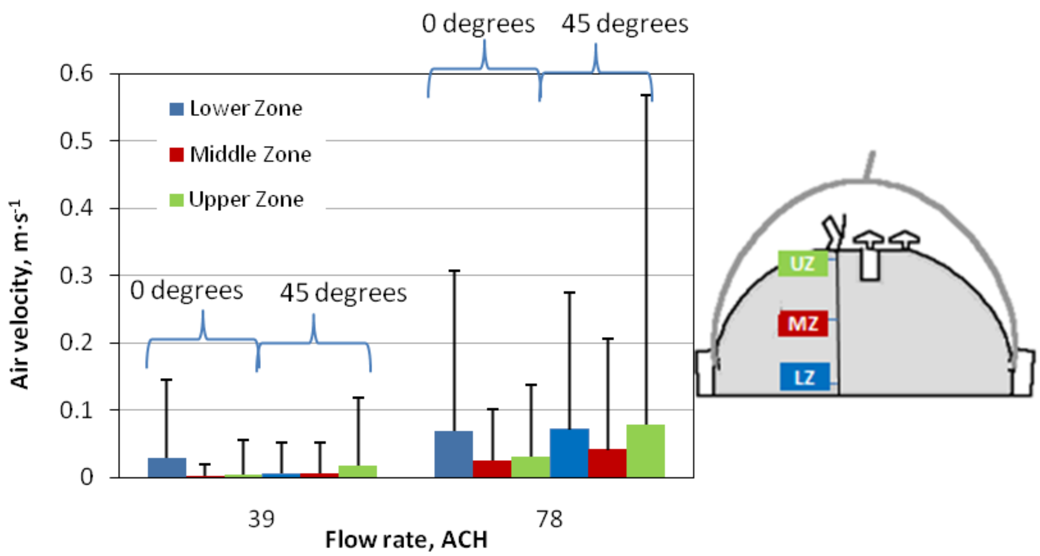

Figure 9. Air velocity profile inside the dynamic flux chamber (DFC) at different distances (zones) from the surface, obtained from different angles (0 and 45 degrees) and 39 and 78 ACH. The vertical bars represent the maximum air velocity of each zone and corresponding air inlet angle. n = 51 at LZ, n = 34 at MZ, and n = 41 UZ for each ACH.

There was significant evidence that air velocities at 2.54 cm from the surface were higher at an air inlet angle of 0 degrees *vs.* 45 degrees and a flow rate of 39 ACH ($p < 0.0001$, SE = 0.006). Although the same was not true at 78 ACH, the mean velocity at 2.54 cm was still numerically higher at 0 degrees with SE = 0.017 (fig. 10). Also, it is important to note that at 78 ACH the overall air velocity inside the DFC was significantly higher for 45 degrees angle than for 0 degrees angle ($P = 0.0073$, SE = 0.003).

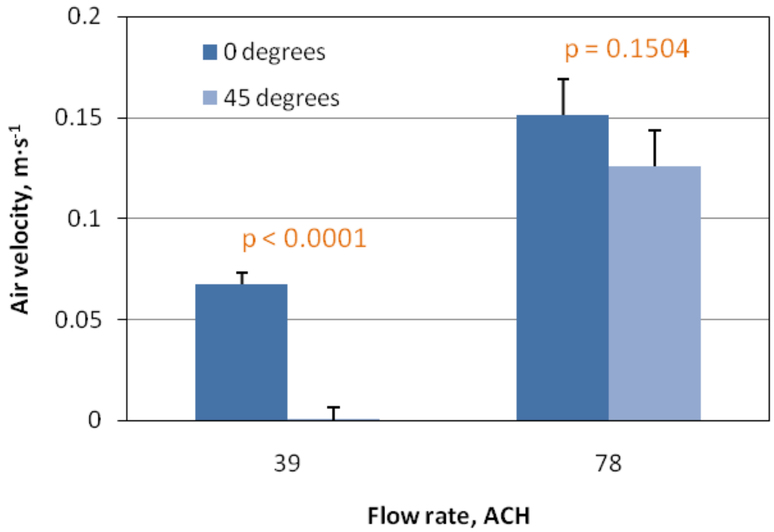

Figure 10. Mean air velocities at 2.54 cm from the surface for 39 and 78 ACH and at air inlet angles of 0 or 45 degrees. n = 17 per combination of angle and ACH.

When looking at the horizontal cross-section there was convincing evidence that air velocities were different for among treatments (overall $p < 0.0001$). Similar to figure 6, the highest speeds were recorded at 10.7 cm from the center (fig. 11), near the chamber wall, where the air inlets were positioned, and there was no difference between the center and 5.3 cm. Standard errors for the different positions according to air exchange rate are listed in table 4.

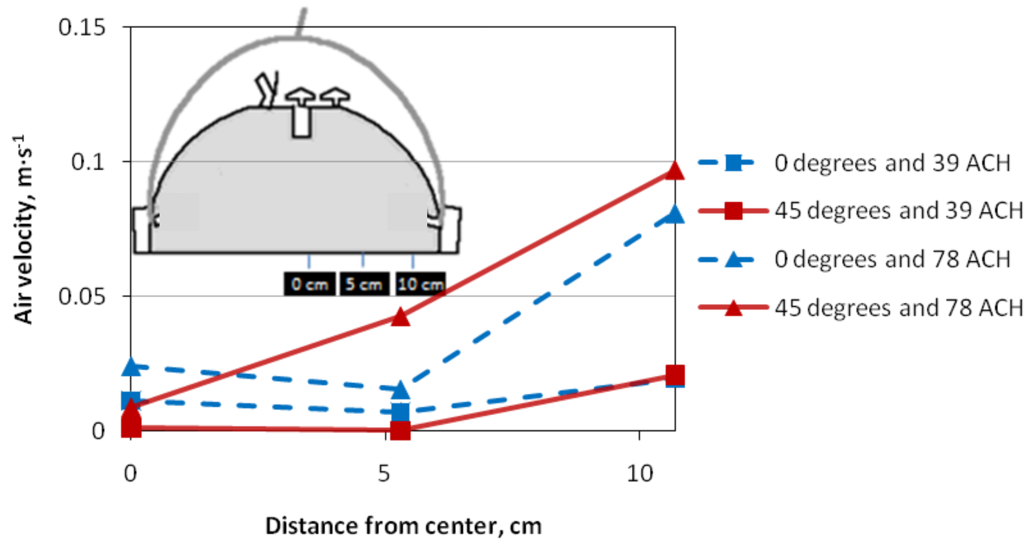

Figure 11. Air velocity profile inside the chamber at different distances from center, obtained from different angles (0 and 45 degrees) and different air exchange rates (39 and 78 ACH). n = 6 at 0 cm; n = 64 at 5.3 cm; and n = 56 at 10.7 cm for each ACH

Table 4. Standard error from air velocities (**$m \cdot s^{-1}$**) at different positions along the horizontal profile of the chamber. Refer to figure 11.

Distance from center, cm	number of measurements	Air flow rate, ACH	
		39	**78**
0	6	0.007	0.012
5.3	64	0.001	0.006
10.7	56	0.003	0.004

Effects of Air Exchange Rate and Velocity on Emissions

Gaseous emissions were expressed in milligrams per minute ($mg \cdot min^{-1}$). The average NH_3 and CO_2 gaseous emissions increased with increasing ACH (fig. 12). There were significant differences in log transformed NH_3 emissions among all ACH (20, 39, 58 and 78 ACH; $p < 0.0001$; table 5). The log transformed CO_2 emissions were also significantly different ($p < 0.002$) for all ACH comparisons except between 58 and 78 ACH ($P = 0.5278$).

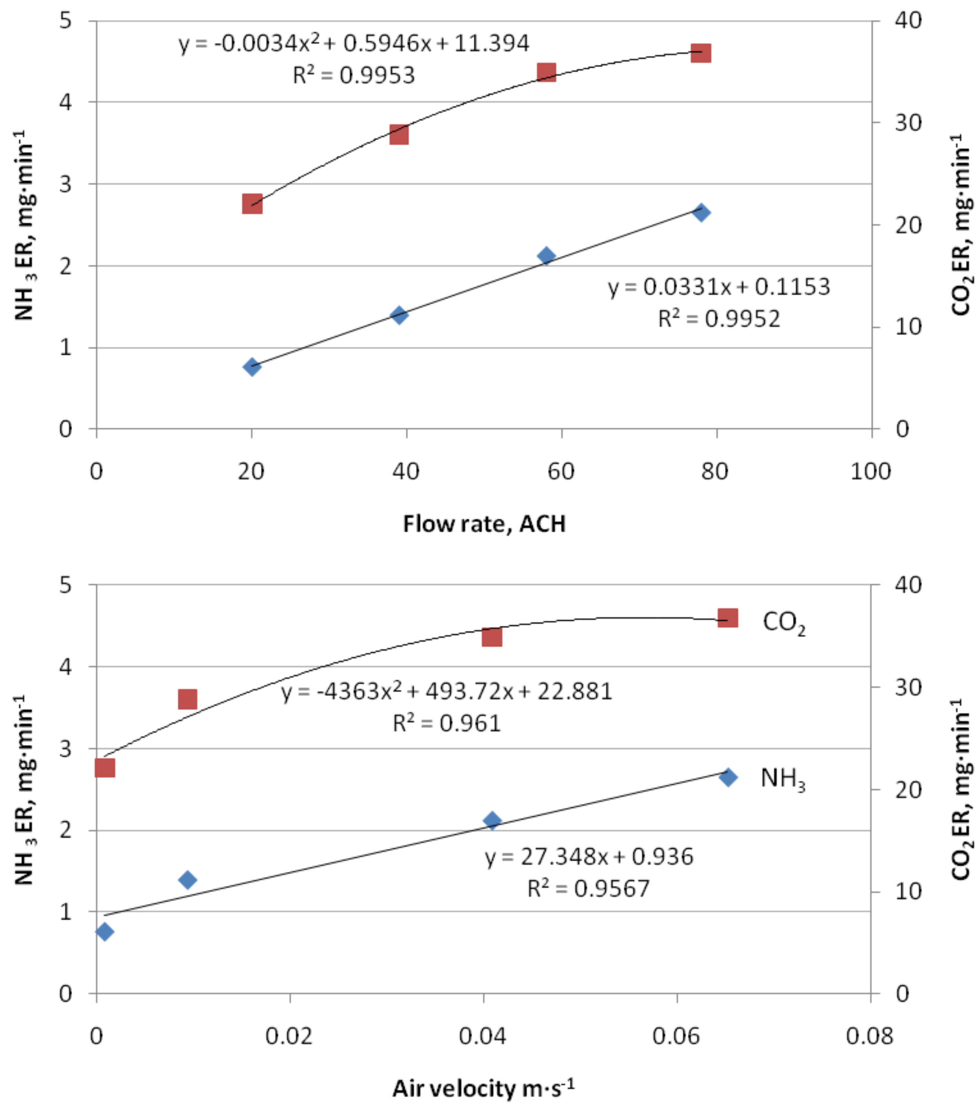

Figure 12. NH_3 and CO_2 emission rate (ER, mg·min^{-1}) at different air exchange rates. Standard errors of 0.028 and 0.033 were obtained for NH_3 and CO_2 log transformed emissions respectively. n = 20

Table 5. Least squared means of NH3 and CO2 emissions at different air exchange rates with corresponding 95% Confidence Intervals (95% CI).

	NH_3			CO_2		
Air flow rate, ACH	ER, mg·min^{-1}	95% CI		ER, mg·min^{-1}	95% CI	
20	0.76	0.72	0.80	22.1	20.8	23.4
39	1.39	1.32	1.46	28.8	27.2	30.6
58	2.12	2.02	2.23	34.9	32.9	37.0
78	2.65	2.52	2.79	36.8	34.7	39.1

As shown in figure 12, a polynomial equation was the best fit for the CO_2 emission data. This, combined with the fact that the CO_2 emissions at 58 and 78 ACH were not significantly different, suggests that emissions will not increase infinitely with increasing air exchange rate. On the other hand, NH_3 emissions increased with ACH and the relationship was best explained with a linear model. Similar models were fit to explain the relationship of ACH *vs.* velocity. Although the models fit well, as noted previously, there was no difference in air velocity between 20 & 39 ACH, thus it is less likely that air velocity was the driving force to the different gaseous emissions under those flow rates. Therefore, it was more likely that fresh air exchange rate itself was the influencing factor in the emission increase. Additionally, it appeared that when ACH was doubled there was approximately 90% increase in NH_3 emissions for the studied flow rates (fig. 13), while for CO_2 there was only 30% increase (fig. 13).

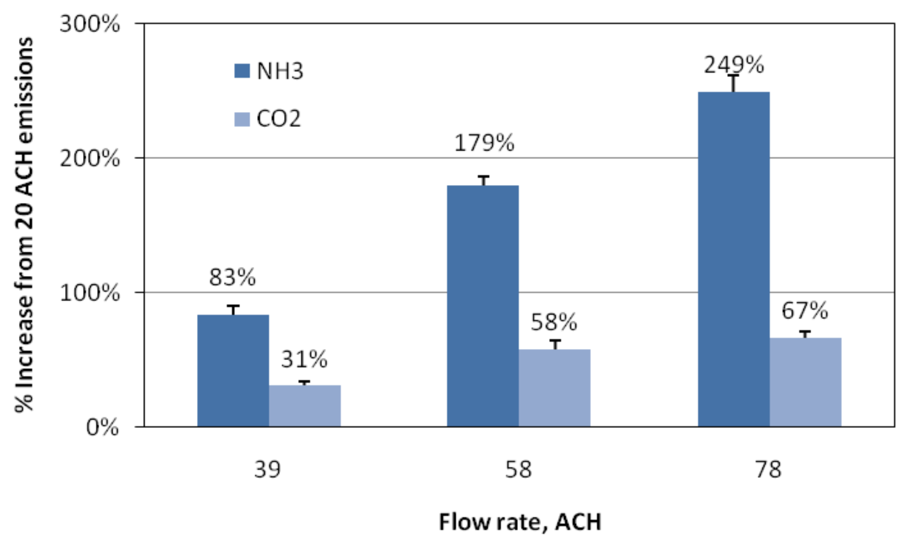

Figure 13. Percent increase in NH_3 and CO_2 emissions from those obtained at 20 ACH.

Effect of Air Inlet Angle on Emissions

The resulting average air velocities inside the DFC, over the surface of the manure (2.54 cm from the surface), for each ACH regimen are listed in tables 6 and 7. Also included in the tables are the least squared means of the gaseous emissions for each ACH transformed to original scale from the log scale, obtained from the "prco glm" function of the SAS program. In comparing overall NH_3 emissions resulting from 0 and 45 degrees air inlet angles and 39 or 78 ACH no significant difference was observed (overall p = 0.3221, n = 20). However, the average NH_3 emissions observed were higher at an angle of 0 degrees compared to 45 degrees. A p-value of 0.0911 (n=10) was obtained when comparing the different angles (0 and 45 degrees) at 39 ACH, which indicates there was suggestive evidence that there was a difference in NH_3 emissions at varying air inlet angles to the chamber. On the other hand, a p-value of 0.6473 (10 observations) was obtained when comparing NH_3 emissions for the different angles at 78 ACH, which indicates no evidence of a difference in emissions existed between the angles.

Table 6. The least squared means NH_3 emission rate ($mg \cdot min^{-1}$) at different air inlet angles and air flow rates in original scale.

	39 ACH					78 ACH				
Angle	**Air velocity $m \cdot s^{-1}$**	**ER, $mg \cdot min^{-1}$**	**95% CI**		**p value**	**Air velocity $m \cdot s^{-1}$**	**ER, $mg \cdot min^{-1}$**	**95% CI**		**p value**
0°	*0.067*	0.622	0.581	0.665	0.0911	*0.152*	1.48	1.37	1.61	0.6473
45°	*0*	0.576	0.539	0.616		*0.126*	1.46	1.34	1.58	

Similarly, the log transformed CO_2 emissions at air inlet angles of 0 *vs.* 45 degrees were not significantly different with (P = 0.6775, n = 20). However, comparing the different angles at 39 ACH showed moderate evidence that there was a difference in CO_2 emissions at varying air inlet angles (P = 0.0341, n = 10). On the other hand, a p-value of 0.1295 (10 observations) was obtained when comparing the different angles at 78 ACH, which indicates there was no evidence that there was a difference in CO_2 emissions at varying air inlet angles to the chamber. The CO_2 emissions were greater at an angle of 0 degrees as compared to 45 degrees at an air exchange rate of 39 ACH, while at 78 ACH the opposite was true (table 7). There was evidence that suggested higher emissions at 0 degree inlet angle, specifically with 39 ACH. This could be related to air velocities over the manure surface. As indicated in the 'Velocity profile' section (fig.10), strong evidence of a higher velocity over the surface was observed for 39 ACH between 0 and 45 degrees. Thus, where there was a difference in velocities, there was evidence of a difference in emissions.

Table 7. The least squared means of the CO_2 emissions ($mg \cdot min^{-1}$) at different angles and air flow rates in original scale.

	39 ACH					**78 ACH**				
Angle	**Air velocity $m \cdot s^{-1}$**	**ER, $mg \cdot min^{-1}$**	**95% CI**		**p value**	**Air velocity $m \cdot s^{-1}$**	**ER, $mg \cdot min^{-1}$**	**95% CI**		**p value**
0º	*0.067*	18.1	16.5	19.9	0.0341	*0.152*	32.4	29.4	35.7	0.1295
45º	*0*	15.6	14.2	17.1		*0.126*	35.6	32.3	39.2	

Conclusions

NH_3 and CO_2 emissions were observed to increase with increasing air exchange rate and air velocities inside the DFC. Air velocities under the chamber were significantly higher for 58 and 78 ACH as compared to 10, 20, 29 and 39 ACH. However, NH_3 and CO_2 emissions were significantly different between 29 and 39 ACH even though there was no significant difference in air velocity between the two ACHs. The best-fit model for CO_2 emission with ACH was a quadratic equation, implying that CO_2 emission would approach maximum when ACH reaches 60. On the other hand NH_3 emission seemed to increase with air exchange rate in a linear fashion for the ACHs tested (20 to 78). In addition, there was evidence of increased gaseous emissions with air velocity over the manure surface as a result of air inlet angle (0 $m \cdot s^{-1}$ at 0 degrees *vs.* 0.07 $m \cdot s^{-1}$ at 45 degrees) for 39 ACH, although this angle effect was not evident at 78 ACH.

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References

Blanes Vidal, V., P. A. Topper and E. F. Wheeler. 2007. Validation of ammonia emissions from dairy cow manure estimated with a non-steady state, recirculation flux chamber with whole-building emissions. *Trans. ASABE.* 50(2): 633-640.

Edeogu, I., J. Feddes, R. Coleman, and J. Leonard. 2001. Odour emission rates from manure treatment/storage systems. *Water Science and Technology*. 44(9): 269-275.

EPA 2001. Emissions from animal feeding operations. EPA Contract No. 68-D6-0011. Research Triangle Park, NC.: U.S. Environmental Protection Agency.

Ferguson, R. B., K. J. McInnes, D. E. Kissel, and E. T. Kanemasu. 1988. A comparison of methods of estimating ammonia volatilization in the field. *Fertilizer Research*. 15: 55-69.

Hoff, J. D., D. W. Nelson, and A. L. Sutton. 1981. Ammonia volatilization from liquid swine manure appled to cropland. *Environmental Quality*. 10:90-95.

Kienbusch, M. R., 1986. USEPA Measurement of gaseous emission rates from land surfaces using an isolation flux chamber, user's guide. EPA Contract No. 60-02-3889. Radian Corporation, EPA/600/8-86/008.

Kissel, D. E., H.L. Brewer, and G. F.Arkin. 1977. Design and test of a field sampler for ammonia volatilization. *Soil Sciencee of America*. 41:1133-1138

Koziel, J. A., D. B. Parker, B. H. Baek, K.J. Bush, M. Rhoades and Z. Pershbacher-Buser. 2005. Ammonia and hydrogen sulfide flux from beef cattle pens: Implications for air quality measurement methodologies and evaluation of emission controls. In Proc. *7th International Symposium*. Paper No.701P0205. Beijing, China: ASABE.

Liang, Y., H. Xin, E. F. Wheeler, R. S. Gates, H. Li, J. S. Zajaczkowski, P. Topper, K. D. Casey, B. R. Behrends, D. J. Burnhan and F. J. Zajaczkowski. 2005. Ammonia emissions from U.S. laying hen houses in Iowa and Pennsylvania. Transactions of ASAE Vol 48(5): 19927-1941. St. Joseph, Mich.: ASABE.

Li, H. 2006. Ammonia emissions from manure belt laying hen houses and manure storage. PhD diss. Ames, Iowa: Iowa State University, Department of Agricultural and Biosystems Engineering.

Liu, Z., L. Wang and D.B. Beasley. 2008. Comparison of three techniques for determining ammonia emission fluxes from broiler litter. *Transactions of the ASAE.* Vol. 51(5): 1783-1790.

LumaSense Technologies. 2007. Photoacoustic field gas-monitor – INNOVA 1412. Santa Clara, CA: LumaSense Technologies Inc.

Messinger, J. J., A. M. Lefcourt, and R. B. Thompson. 2001. Construction and validation of small mobile wind tunnels for studying ammonia volatilization. *Applied Engineering in Agriculture.* 17(3): 375-381.

National Academy of Science. 2003. A*ir emissions from animal feeding operations current knowledge, future needs.* Washington D.C.: The National Academy Press.

Ni, J. (1999). Mechanistc models of ammonia release from liquid manure: A review. *Agricultural Engineering Research.* 72: 1 – 17

Pedersen, S., V. Banes-Vidal, H. Joergensen, A. Chwalibog, A. Haeussermann, M. J. W. Heetkamp and A. J. A. Aarnink. 2008. Carbon dioxide production in animal houses: A literature review. Agricultural Engineering International: CIGR Ejournal. Manuscript BC 08 008, Vol. X.

Pratt, E. V., S. P. Rose, and A. A. Keeling. 2002. Effect of ambient temperature on losses of volatile nitrogen compounds from stored laying hen manure. Bioresource Technology. 84 203-205.

Ramsey F. L. and D. W. Shafer. 2002. *The statistical sleuth: a course in methods of data analysis*. 2nd ed. Pacific Grove, CA: Duxbury Press.

Rhoades, M. B., D. B. Parker, B. Auvermann, N. A. Cole, Z. Perscbancher-Buser, and R. E. DeOtte. 2005. Factors affecting emissions measurements with surface isolation flux chambers. ASAE paper No. 054026. St. Joseph, Mich.: ASABE.

Ryden, J. C., and D. R. Lockyer. 1984. Evaluation of a system of wind tunnels for field studies of ammonia loss from grassland through volatilization. *Science of Food and Agriculture.* 36(9): 781-788.

Symons, G. E., and B. Morey. 1941. The effect of drying time on the determination of solids in sewage and sewage sludges. *Sewage Works* 13: 936.

Wheeler, E. F., P. A. Topper, and T. L. Richard. 2007. Validation of flux chamber technique for estimate gas emission in situ from naturally-ventilated facilities. In *Proc. International Symposium on Air Quality and Waste Management for Agriculture Conf.*, 701P0907cd.

Whitehead, D. C., and N. Raistrick. 1991. Effect of some environmental factors on ammonia volatilization from simulated livestock urine applied to soil. *Biology and Fertility of Soils* 11:279-284

Chapter 3: Evaluation of a Dynamic Flux Chamber for Assessing Gaseous Emissions and Treatment Effects of Poultry Manure

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Abstract

Mobile air emissions monitoring units (MAEMUs) are capable of precise and real-time emission measurement, and are considered the norm for continuous intensive monitoring from mechanically ventilated animal facilities. However, their relative immobility and high cost are limiting a widespread use. Meanwhile the need to quantify air emissions from animal feeding operations (AFOs) continues to rise. Exploration of practical means to reduce air emissions also calls for less sophisticated but reasonably dependable methods to quantify the treatment effect. Correspondingly, several methods, such as gas-washing, micro-meteorological, wind tunnel, flux chamber, and mass-balance methods, have been employed to accommodate different measurement needs. Flux chambers have the advantages of being portable, small size, low cost, and less labor requirement. The objectives of this study were to assess gaseous (NH_3 and CO_2) emissions of high-rise layer houses with a dynamic flux chamber (DFC) *vs.* MAEMU and to evaluate the adequacy of using the DFC to determine the relative efficacy of dietary regimens on ammonia emissions from the layer manure. The preliminary data (37 measurements) showed that NH_3 emission from the manure surface measured with the DFC was 8% to 16% that of the whole barn measured with the MAEMU, while CO_2 emission from the manure surface was 1% to 4% of the barn emission. The preliminary results obtained with DFC concerning the dietary efficacy of ammonia emission reduction were mixed as compared to those obtained with the MAEMU.

Keywords: Ammonia, carbon dioxide, flux chamber, air emissions, mitigation

Introduction

In modern livestock and poultry barns, proper indoor air quality is imperative in maintaining the health of workers, animal welfare and productivity. Ammonia (NH_3) and carbon dioxide (CO_2) are two of the major pollutants emitted from animal feeding operations (AFO) because of the potential health risks and impact on the environment. It has been reported that in poorly ventilated barns, high concentrations of NH_3 coincided with symptoms associated with toxic or inflammatory effects on the respiratory tract of workers as well as adverse effects on animal health (Carlile, 1984; Jacobson et al., 2003). In addition, NH_3 volatilization leads to “acid rain” in the vicinity (van Breemen et al., 1982). CO_2 also causes human health risks at concentrations of 1% (10000 ppm) or higher. The CO_2 toxicity and its effects increase with concentration, which may exist inside a facility when ventilation failure occurs. Furthermore, CO_2 is considered one of the major greenhouse gases that contribute to global warming.

NH_3 is mainly produced by the decomposition of nitrogenous compounds in manure through the inefficient conversion of feed nitrogen to animal products. Its characteristic strong odor makes it easily detectable at 5 to 10 ppm. CO_2, on the other hand, is odorless and produced by animal respiration and manure decomposition. The generation of both gases from poultry facilities occurs through the degradation of uric acid in the manure, although

CO_2 is primarily from animal respiration (Pedersen et al., 2008). Undigested nitrogen in feces will also be mineralized to NH_3 (National Academy of Science, 2003; Zhao, 2007). Gaseous emissions are affected by environmental conditions, ventilation rate, dietary composition, animal activities, animal life stage, manure properties (e.g. moisture content, pH), and manure management practices (Liang et al., 2005).

Mobile air emissions monitoring units (MAEMUs) are capable of precise and real-time emission measurement and are typically used for continuous, intensive monitoring of emissions from mechanically ventilated animal facilities. Gaseous emission rate (ER) is quantified as the product of concentration difference (between exhaust and inlet air) of the pollutant and the ventilation rate (Q) through the facility (Li et al., 2008a). It involves measurement of airflow rate of the exhaust or supply fans under specific static pressure and monitoring fans run-time. Among the studies that involve use of MAEMU by our research group at Iowa State University was the comparison of dietary treatments of EcoCal™, dried distillers grains with solubles (DDGS) and control diets. Recent laboratory studies showed a 40 – 60% reduction in NH_3 emissions from laying-hen manure of an EcoCal™ diet, while a study conducted in a commercial operation showed an emission reduction of up to 23.2% (Li et al., 2008b). Also, the higher supply of DDGS in animal diets, because of the rapid increase in production of ethanol encourages comparison (Waldroup et al., 2007). Roberts et al. (2007) found a reduction of approximately 40% in NH_3 emission from manure of laying hens fed 10% dietary DDGS. In spite of the MAEMU's precision and real-time measurement capabilities, its relative immobility and high cost limits the widespread use for baseline emission and mitigation studies. Several other methods, such as gas-washing, micro-meteorological, wind tunnel, flux chamber, and mass-balance methods have been employed to accommodate different measurement needs (Koziel et al., 2005; Liu et al., 2008). Flux chambers have the advantages of being portable, small size, low cost, and less labor requirement.

The objectives of this study were to assess gaseous (NH_3 and CO_2) emissions of high-rise layer houses measured with the DFC *vs.* with the MAEMU, and to evaluate the adequacy of using the DFC to determine the relative efficacy of dietary regimens on NH_3 emissions from the layer manure.

Materials and Methods

Site Description

Mobile Air Emissions Monitoring Unit (MAEMU)

The MAEMUs are capable of precise and real-time emission measurement for mechanically ventilated animal facilities. A detailed description of the MAEMU and operation can be found in Burns et al. (2005), while Li et al. (2008b) described its use at the studied site. The gasses of interest (NH_3 and CO_2) were measured with a photoacoustic multi-gas analyzer (INNOVA model 1414, INNOVA AirTech Instruments A/S, Ballerup, Denmark). The gas analyzers were checked weekly with calibration gasses and recalibrated as needed. Air samples were drawn from two composite locations (east and west parts) in each house as well as from outside locations to provide ambient background data. Ventilation rates were measured by continuously monitoring runtime of the fans whose performance curves were determined in-situ.

High-rise Layer House Description

High-rise layer houses are two story buildings, which contain stair-step cage systems in the upper story with manure collected and stored in the lower story of the building. Ventilation fans were located in the sidewalls of the manure collection and storage area with air flow passing down through the cages and over the accumulated manure to remove gasses and moisture evaporating from the manure. Eggs are collected on belts and transported to packaging stations. The houses (at the site in central Iowa) had an east – west orientation, with an approximate length of 180 meters and width of 27.4 meters (fig. 1). Ventilation fans are located on both longitudinal sidewalls at the manure storage level.

Each house contained approximately 255,000 white leghorn (Hy-line W-36) laying hens, and each was supplied with a different diet. Including a diet containing 3.5% EcoCal, containing 10% DDGS, and a control diet containing neither EcoCal nor DDGS. All other ingredients were included in the proprietary commercial diet to supply nutrients to meet or exceed the NRC (1994) recommendations.

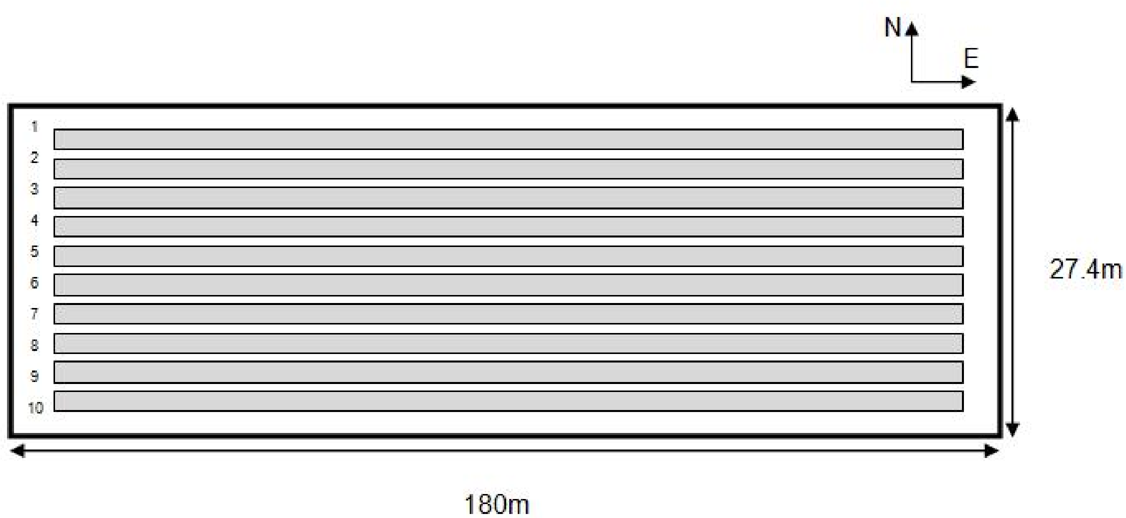

Figure 1. A sketch of the top view of the lower story of the high-rise barns sampled, showing the pile numbering scheme.

Manure Management and Handling

Manure was collected on dropping board areas located directly under each cage, and was scraped three times per day. Manure fell to the lower story of the building (fig. 2), and over time manure accumulated to form piles across the length of the barn. Ten manure piles were formed and labeled as shown in figure 1. Mixing fans were located at the manure level on every other isle to facilitate manure drying. Manure from the lower story was removed once or twice a year and land applied as fertilizer.

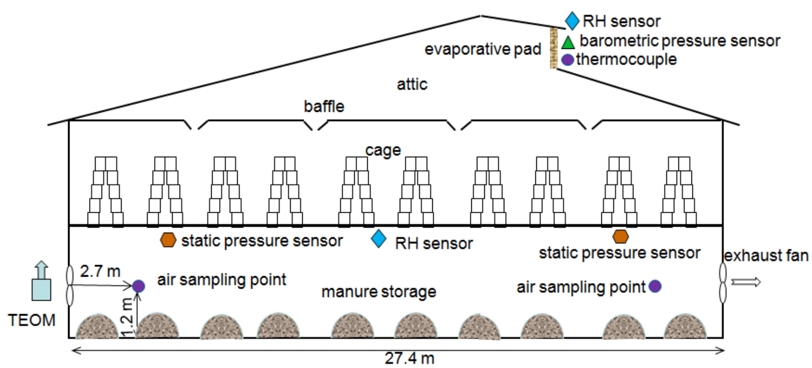

Figure 2. Sketch of a cross section view of a high-rise layer house. Contains outline of MAEMU instrumentation inside the house. (Li et al. 2008)

Gaseous emission estimations from flux chamber methods only account for emissions from the manure in the lower story of the building. The estimation does not consider emissions from manure located on the dropping board areas, as well as other sources of emissions like spilled feed, wash water, and animal respiration (CO_2) . Therefore, an “underestimation” of gaseous emissions for the entire house is expected. Additionally, there are several sources of variability due to factors affecting manure properties, such as proximity of manure areas to mixing and ventilation fans, water leakage, bird activity, and operational states fans and scrapers.

Dynamic Flux Chamber (DFC) System

The DFC system was used to measure NH_3 and CO_2 and was the same as the one described in Chapter 2. Throughout the comparative study flow through the DFC was kept at approximately 39 air changes per hour [ACH (8 L·min^{-1})], and the air inlets were maintained at 45 degrees with respect to the manure surface. In addition an in-line air purification filter containing zeolite was used to remove most, if not all, NH_3 from the incoming (in-barn) air to the DFC to have a relatively NH_3-free supply air from location to location. Air was supplied with a Gast DDL linear air pump (Gast Manufacturing, Benton Harbor, MI) and the flow rate was controlled using a Dwyer flow meter (model RMA21SSV) with a 0 to 10 L/min range. The air was sampled using a photoacoustic multi-gas monitor (INNOVA 1412, AirTech Instruments A/S, Ballerup, Denmark). Figure 3 illustrates a sketch of the DFC system and all the components.

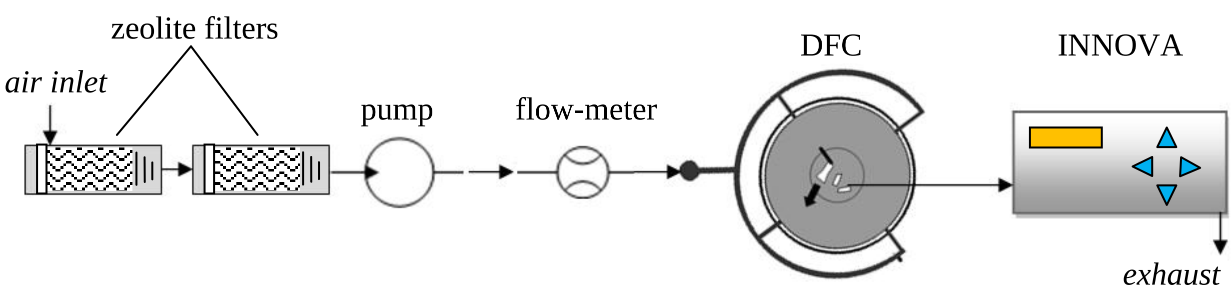

Figure 3. Schematic representation of the dynamic flux chamber (DFC) sampling system

Zeolite as a Filter Material

Inside a ventilated animal facility gas concentrations may vary over time, which changes what the perceived gas concentration is outside the chamber. In addition, NH_3 emission may be inhibited by high NH_3 concentrations. Thus, when attempting to estimate

NH_3 emissions from a DFC an NH_3 free supply air to the system that is not greatly influenced by the emission source (manure) is desirable.

The ion-exchange and adsorption properties of zeolite for binding NH_3 have been well documented (Mumpton and Fishman, 1977; Bernal et al., 1992; Kithome and Paul, 1999; Cai et al., 2006; Li et al., 2008c), and its application as a filter material for a DFC system is warranted. Additionally, the low cost of zeolite compared to other filter materials, such as activated carbon, makes it an attractive alternative.

In turn, the DFC system was fitted with 2 in-line zeolite filter columns filled to a depth of approximately 14 cm on 28 cm columns (5.5 cm ID and 7 cm OD). The onsite efficiency of the filters was determined through background tests performed prior to DFC tests on the manure piles. These tests are described in the subsequent section. While the background tests were being performed, NH_3 and CO_2 concentrations were being sampled simultaneously by the MAEMU. Filter efficiency was determined by comparing the average concentration after zeolite filtration to the one obtained from the closest MAEMU sampling port during the same period of time; as $ave\ NH_3\ decrease = [NH_{3(MAEMU)} - NH_{3(background\ test)}] * [NH_{3(MAEMU)}]^{-1}$. If the DFC was located in between sampling ports, then the average NH_3 concentrations for the entire house was used.

Over the course of 12 days, 64 background tests were performed, which covered all seasons of the year and a broad range of NH_3 concentrations. The minimum and maximum NH_3 concentrations obtained from the MAEMU during a background test were 2.3 and 81 ppm respectively. The average decrease in NH_3 concentrations for all measurements was 90% (SE = ± 2% for n = 64). The efficiency of the zeolite filter seemed to increase with NH_3 concentrations. When NH_3 concentrations from the MAEMU were above 20 ppm the average decrease in NH_3 was 97% (SE = ± 0.3% for n = 40). On the other hand, when MAEMU concentrations were less than 4 ppm the decrease in NH_3 concentrations were as low as 10%. The reduced efficiency could be attributed to less contact between the zeolite surface area and the NH_3 particles. Also, the proximity of the low concentrations to instruments' detection limit and differences in the sample may have contributed to some extent. Additionally, the near NH_3 free air could have been freeing NH_3 attached to the zeolite from previous trials. Figure 4 shows NH_3 concentrations before (as measured with MAEMU) and after the zeolite filters.

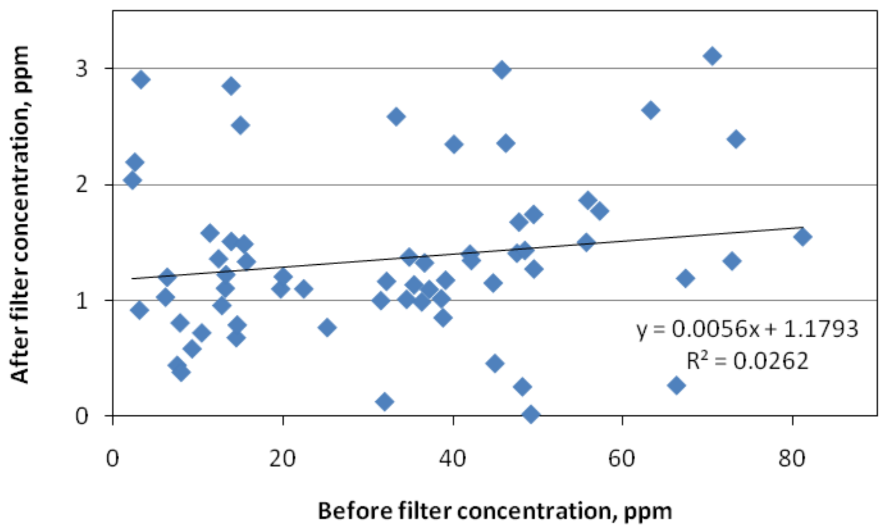

Figure 4. NH_3 concentrations before and after the zeolite filtration. n = 64, 5.5 cm ID and 14 cm depth

CO_2 concentrations did not seem affected by the zeolite filters as concentrations closely matched the ones obtained by the MAEMU (fig.5). Further studies of zeolite use as filter material are warranted.

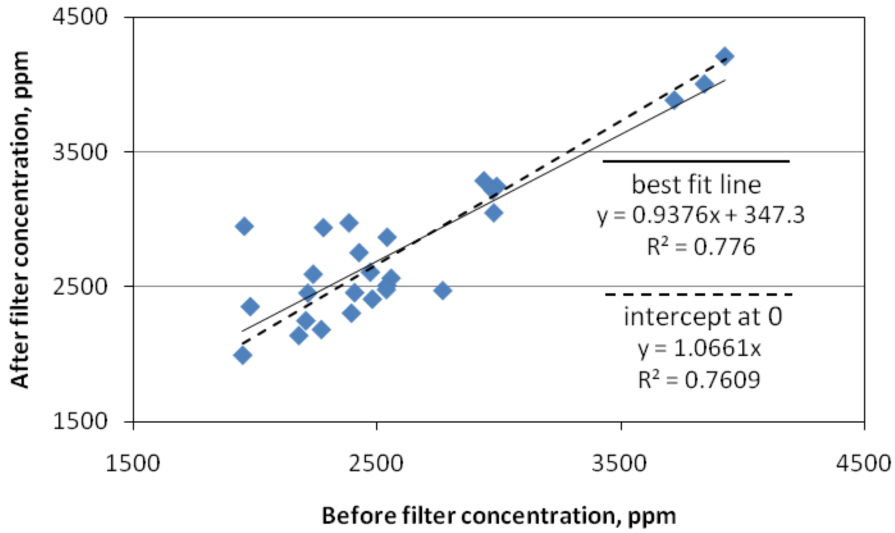

Figure 5. CO_2 concentrations before and after the zeolite filtration. n = 27, 5.5 cm ID and 14 cm depth

Farm Measurements

Figure 6 shows the sample locations, which were chosen to determine spatial variation of NH_3 concentrations in longitudinal and latitudinal directions. NH_3 and CO_2 emissions measured with the DFC were also compared to those measured with the MAEMU for the three high-rise layer houses under three different dietary treatments (EcoCal™, DDGS and control). A location was chosen at approximately the middle point between two adjacent mixing fans in the manure store level and a light bulb adapter was placed in one of the lights to provide power to the DFC operation. The manure store mixing fans were used to facilitate the manure drying. A position too close to one of these fans may not provide an adequate representation of manure properties throughout the house. The DFC was placed approximately mid-way between the peak and the base of the pile. A plastic bag was placed on top of the chamber to prevent any manure from falling on it. The air-supply inlet of the system was hung at a height of approximately 3 m (10 feet) above the floor.

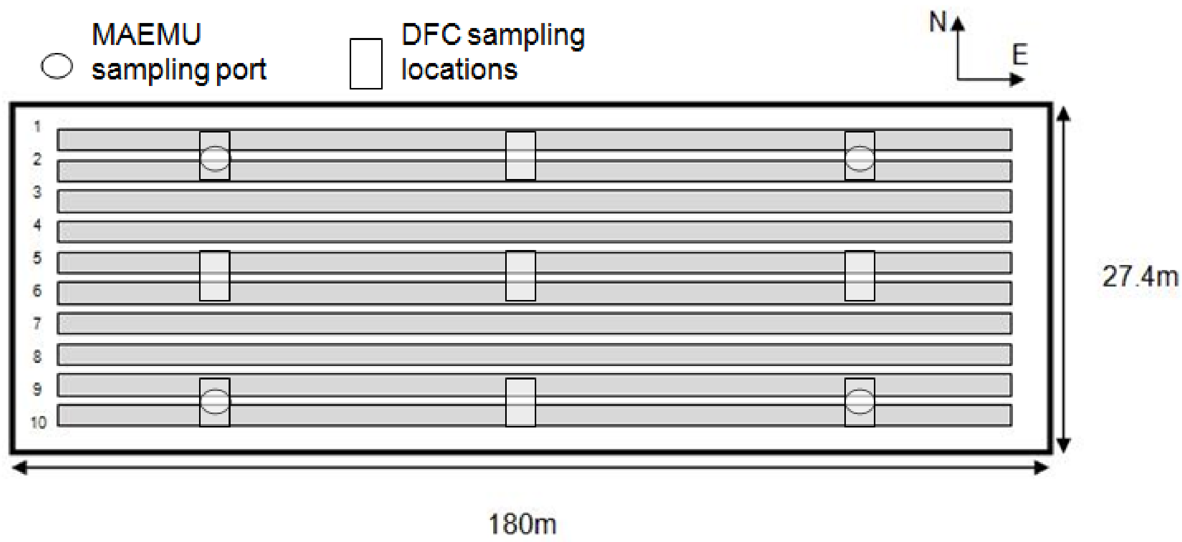

Figure 6. A sketch of the manure piles in each of the three barns sampled, showing the numbering scheme. The MAEMU's sampling ports are located between piles 1 & 2 and 9 & 10. DFC samples were taken from piles 1, 2, 5, 6, 9 and 10.

Efficiency of the zeolite filters was checked prior to the tests on the manure piles in each house to determine the passage rate of NH_3 through the filters and quantify the background NH_3 and CO_2 that would enter the DFC. The tubing was adjusted such that air passed directly from the zeolite filters to the INNOVA by by-passing the DFC (fig. 7). Normally, the test lasted for 10 min, except when the INNOVA had not been used for a long time, in which case sampling was done for 20 min to allow the INNOVA to warm up. The last 5 min measurements were averaged to get the base concentration of NH_3 and CO_2.

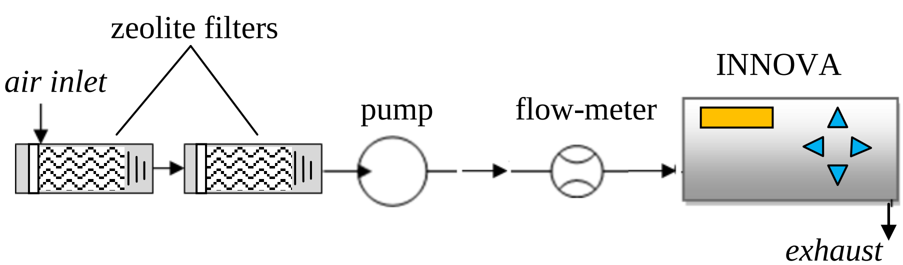

Figure 7. Sketch of set up to measure background gas concentrations.

To test the manure piles, the flow meter was adjusted so that air went into the DFC at 8 L·min^{-1} (i.e. 39 ACH). During sampling, the INNOVA was set to sample every 30 s and gas concentrations were automatically recorded in the INNOVA internal memory and retrieved after each farm visit. In addition, the concentrations were also manually recorded every 5 min, which allowed the operator to determine when concentrations stabilized. If the difference between the two consecutive concentration readings was less than 5%, the equilibrium of gaseous emissions was obtained and the DFC was moved to the next location. If not, the concentrations were continuously recorded on the sheet every five minutes until the last two concentration differences were within 5%. Figure 8 shows a graph for a set of concentration measurements in one location.

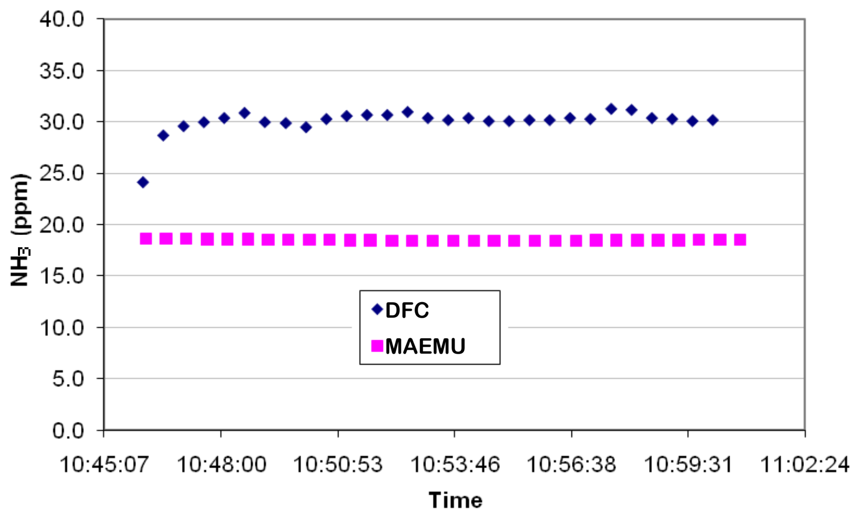

Figure 8. Example graph of on-site NH_3 concentration measurements from the DFC and MAEMU

In a research study conducted by Boriack et al (2005) there was no significant change in the concentration output due to chamber adsorption when a clean chamber was exposed. The chamber in their study consisted mainly of stainless steel as did the chamber in our study. Therefore, chamber adsorption was considered negligible, as well as the adsorption due to the tubing material (Shah et al, 2006).

A flux from the DFC is obtained as follows:

$$F = \frac{Q(C_e - C_i)W_m T_{std} P_a}{10^6 V_m T_a P_{std} A_{DFC}} \quad [1]$$

where:

F = flux, g min^{-1} m^{-2}

Q = flow rate going into the chamber, L min^{-1}

C_e = gas concentration of air exiting the chamber, ppm

C_i = gas concentration entering the chamber, ppm

W_m = molecular weight, g/mol

V_M = molar volume at standard temperature (0^0 C) and pressure (101.325 kPa), 22.4 L mol^{-1}

T_{std} = standard temperature, 273.15 K

P_{std} = standard pressure, 101.325 kPa

P_a = barometric pressure, 97 kPa

T_a = temperature of the sample air, 293.15 K

A_{DFC} = DFC area, 0.0804 m^2

In order to estimate the emission rate of the entire barn through the DFC, the manure pile surface area was estimated. The manure profile was measured by placing a measuring tape directly on the manure and over the pile, covering the entire perimeter. Three profile measurements were taken from each pile in the barn (east, middle and west), a total of 30 measurements per barn for each run. Since manure was removed from the houses multiple times during the study, samples were only taken when the pile profile was between 1.5 and 4.3 m. A weighted average of the emission rates was determined, where piles 1, 2 & 3 were considered ‘north’, 4, 5, 6 & 7 ‘middle” and 8, 9 & 10 ‘south’ (fig. 4) resulting in the following equation:

$$ER_{manure} = \overline{F_{north}}\left(\overline{A_1} + \overline{A_2} + \overline{A_3}\right) + \overline{F_{middle}}\left(\overline{A_4} + \overline{A_5} + \overline{A_6} + \overline{A_7}\right) + \overline{F_{south}}\left(\overline{A_8} + \overline{A_9} + \overline{A_{10}}\right) \quad [2]$$

where:

ER_{manure} = estimated emission rate of the manure piles through DFC, g min^{-1} $barn^{-1}$

F_i = Flux at the north, middle or south locations, g min^{-1} m^{-2}

A_i = Average area of three measurements of a pile (1 through 10), m^2, calculated from measured perimeter and length of the pile.

Manure Pile Profile

To determine manure pile variability within each barn a factorial experiment that considered 3 independent variables was developed. The variables were the barn (3 barns), the manure pile number (10 piles per barn, fig. 1), and a location on the pile (3 locations per pile: east, middle or west), blocked by the day of measurement collection. The measurements were analyzed by a 3-way ANOVA using the “proc glm” function of the SAS program. The barns were identified by dietary treatments; DDGS, control, and EcoCal.

Manure perimeter measurements were completed for 8 ~ 9 days from May to August (2009). Measurements within each pile were gathered within a 2-hour period.

Pile perimeter generally increased with time, except for the periods when birds had been removed or new flocks were placed. Figure 9 shows how the overall mean pile perimeter increased with time. Although the barns were identified by dietary treatment, no attempt at a relation among diets and pile size variability was done.

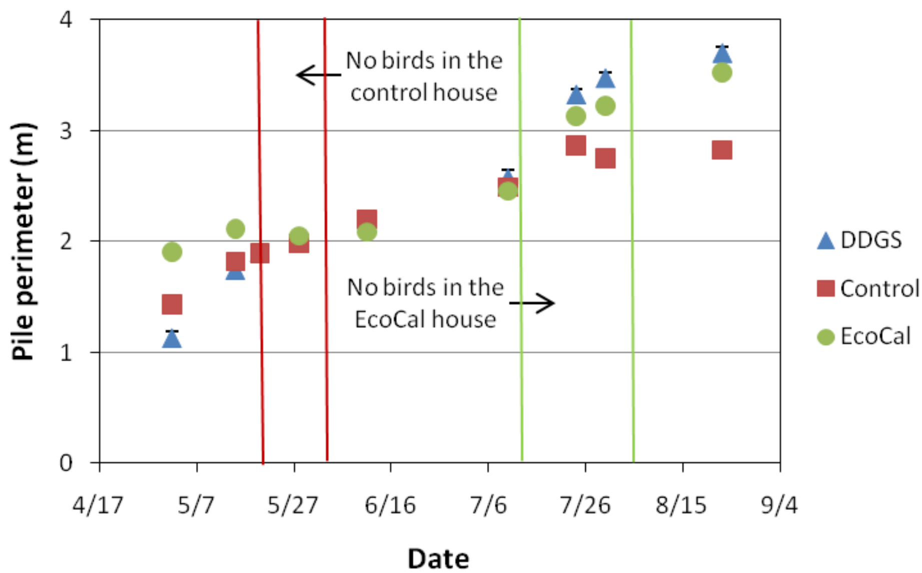

Figure 9. The average pile perimeter for each day and barn. There were a total of 30 measurements per barn per day.

Convincing evidence was found that at least one pile was different within all three barns. When looking at the north to south orientation (fig. 10) of the barns (10 piles with 3 measurements per pile, and done 9 times) a significant difference was observed with p-values of less than 0.0001 for all barns. Similarly when looking at the east to west orientation (fig. 11) there was convincing evidence of a difference with p-values of 0.0006, and less than 0.0001 for barns being administered DDGS and control diets respectively. Meanwhile, the barn being administered the EcoCal diet showed suggestive evidence of a difference in pile size on the east to west orientation with a p-value of 0.0598.

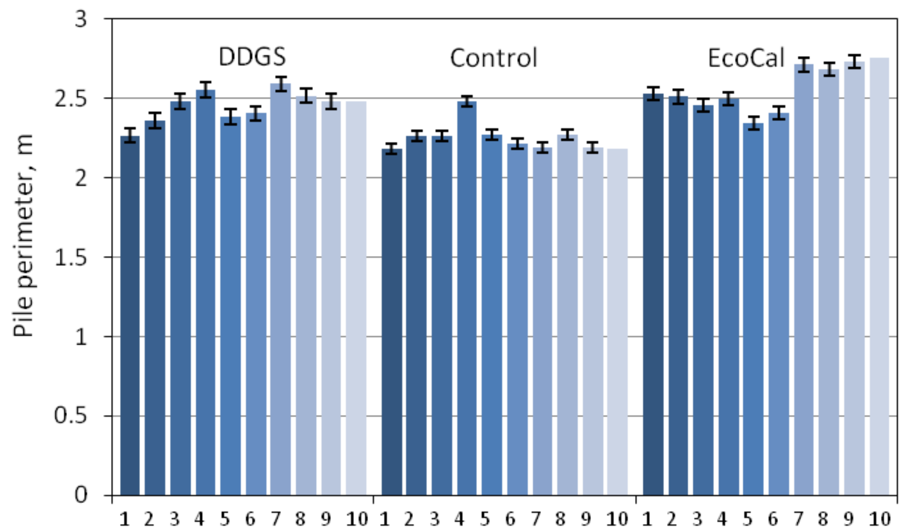

Figure 10. Least squared means of the pile size from the three barns for every manure pile (north to south orientation). 27 measurements per pile for DDGS and control barns, and 24 measurements per pile for the EcoCal barn.

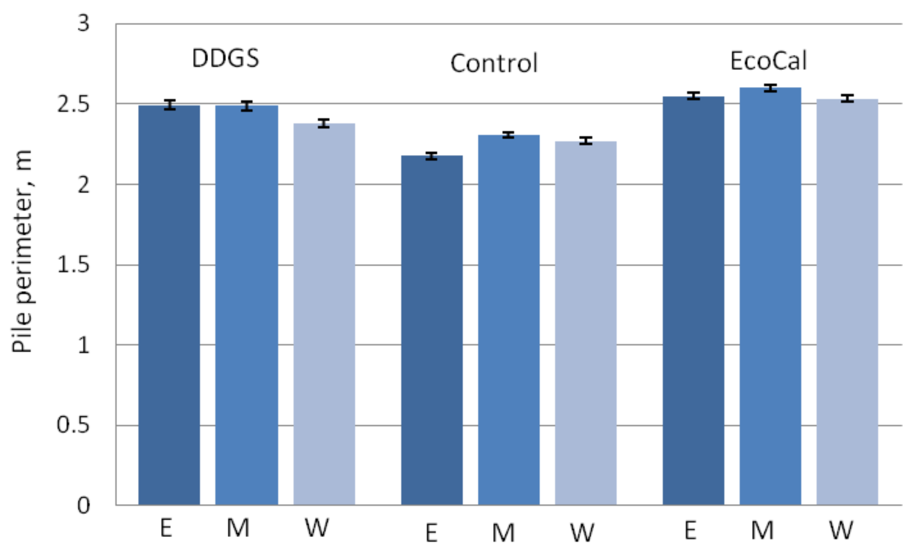

Figure 11. Least squared means of the pile size from the three barns for the east to west orientation. 90 measurements per location for DDGS and Control barns, and 80 measurements per location for the EcoCal barn

Manure pile size variation could be impacted by various factors. In some instances manure removal could last more than a week or it could be done in portions, instead of all of it during the same period, resulting in different pile sizes. Similarly, the placement of the birds is approximately done over a week span; consequently some areas may receive bird defecation at an earlier starting time. Another factor is manure accumulation in beams separating the two levels in the barn, preventing manure from settling in the lower story. Additionally, operational parameters affect pile profile, including: loss of moisture of one area over another due to the proximity to fans, personnel presence, water leaks, and malfunctioning scrapers. In addition, after manure piles get to a certain height it is common for personnel to knock them down in order to get around.

Although variation in manure pile profile exists within a house extensive profile measurements should provide a good estimation of the manure surface area. In summary, High-rise layer houses have the advantage of having a uniform pile profile throughout most of the year as compared to other livestock facilities, which makes the quantification of the manure surface area (emission source area) attainable without many problems. In turn, emission estimation from the manure piles for the entire house is possible. It is important to note that other sources of emission exist that are not accounted for in DFC measurements, such as spilled feed, wash water, manure in the second floor, and animal breathing, which especially affects CO_2 emissions. Some variation is expected on manure properties from the effect of mixing fans and ventilation fans over certain manure areas. Other factors that may contribute to non-uniform manure properties are operational status of fans and manure scrapers, water leaks, age etc.

Experimental Design

Measurements were grouped by seasons. Summer included the months of June, July and August; autumn the months of September, October and November; winter the months of December, January, and February; and spring the months of March, April and May. Statistical analyses were conducted to determine an adequate sampling scheme inside the houses, considering spatial variation of gaseous emissions, which may broadly differ inside livestock houses (Brewer and Castello, 1999). Several aspects taken into consideration were the east – west and north – south cross sections of the barn, as well as the emission variation between neighboring piles and along the pile profile. The Fisher F-test was conducted to determine the presence of a significant difference among the samples at the (a) east, middle and west of the barn; (b) north, middle and south of the barn; and (c) the top, middle and bottom of the pile profile. The Student t-test was performed to determine the presence of a difference between neighboring piles. In addition, a comparison between the DFC and MAEMU ER values was performed and the Student t-test was conducted to compare the control diet *vs.* the (i) DDGS diet and (ii) EcoCal^{TM} diet. A p-value of < 0.05 was considered to be evidence of a significant difference in the comparisons. The significance (strong *vs.* weak evidence) of the obtained p-values was interpreted as indicated by Ramsey and Shafer (2002).

In the analyses, samples were paired according to location and date, because great variability in gas concentrations was observed from week to week. There were days when samples were not taken from all locations.

Results and Discussion

Spatial Variation of Emission Rates

Manure properties and gaseous emissions may vary along the length of the barn due to spatial variations in temperature, moisture content caused by water leakage and manure-drying fans and different microbial activities in the piles. The barns were east – west orientated, therefore locations were tested from the east, middle and west to determine if a difference in NH_3 emissions from the piles exists. The east, middle and west denominations were matched according to pile number (fig. 12) and date. There was no statistically significant difference in NH_3 concentrations between the three locations during the autumn months (P = 0.97) and weak evidence during the winter months with a p-value of 0.13 (fig. 12).

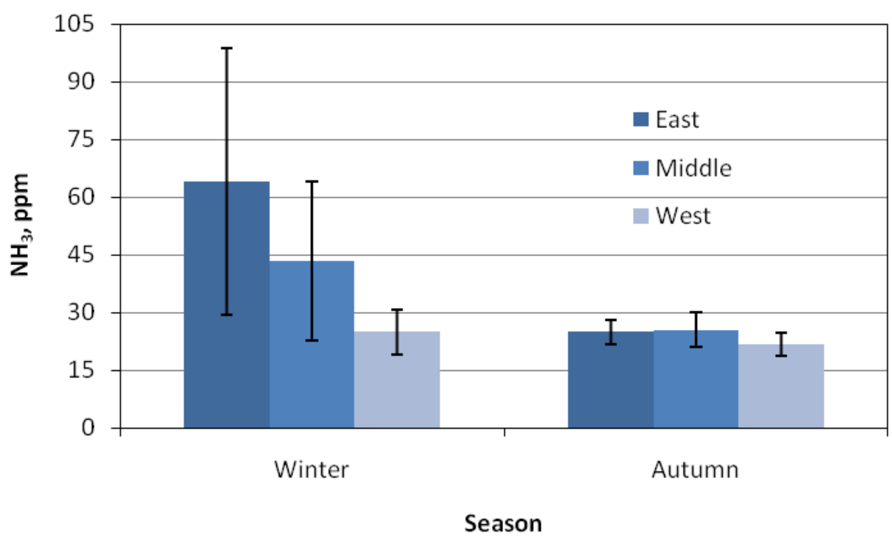

Figure 12. Longitudinal variations of NH_3 concentrations for different seasons (winter and autumn), as measured with the DFC placed on the surface of the manure piles. n = 4 per location during winter, and n = 14 per location during autumn

Similarly, with the north-south cross-section the NH_3 emitted from the piles may vary. Samples were taken from the north, middle and south and matched according to date and pile number (fig. 6). Piles 1 & 2 represented the north, 5 & 6 represented the middle and 9 & 10 represented the south. During winter there was no difference among locations, as opposed to autumn, where the NH_3 concentration was lower in the south piles compared to the north and middle piles (P = 0.008; fig. 13). Because of this potential difference, the north, middle and south locations should be considered in the sampling scheme to determine emission rates.

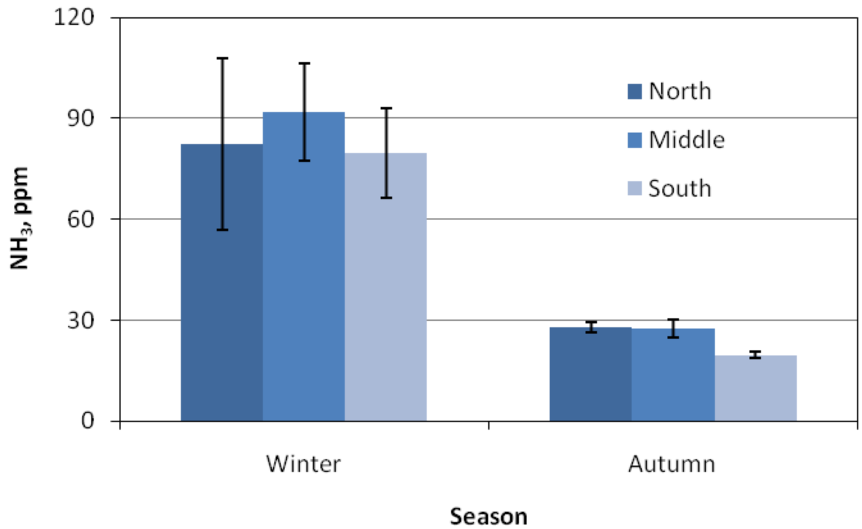

Figure 13. Variations in NH_3 concentrations across the width of the barns duirng different seasons (winter and autumn) as measued with the DFC placed on the surface of the manure piles. n = 8 per location during winter, and n = 14 per location during autumn.

A comparison between two neighboring piles (piles next to each other: 1 & 2, 5 & 6, 9 & 10) was made. Sampling areas were taken at approximately the middle of the pile and on the side that faces its neighbor. Results show that there was not a significant difference between the NH_3 concentrations of two neighboring piles. A paired-t analysis was used to compare the NH_3 concentrations from any two neighboring piles; results are shown in Figure 14. The NH_3 concentration measured from neighboring manure piles was not different in the autumn or winter seasons (P = 0.725 and P = 0.984, respectively).

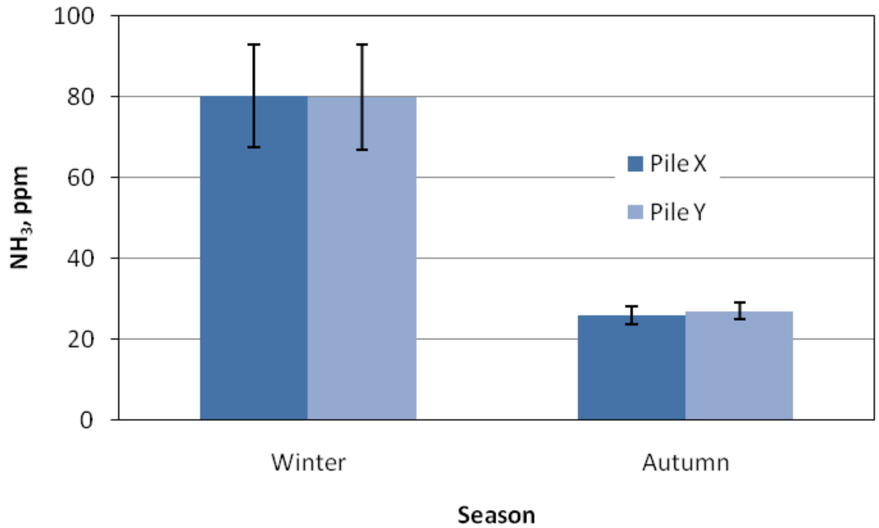

Figure 14. Example of average NH_3 concentrations from any two neighboring piles measured with the DFC on the same day. n = 17 per pile during winter, and n = 14 per pile during autumn.

Other positions worth considering are those along the pile profile. Manure in a pile may have different properties and therefore release different quantities of NH_3 gas. As the manure accumulates and forms the pile, it is assumed that the manure at the top of the pile contains more recent deposition and hence is wetter than the lower portion of the pile. A comparison along the piles' cross section (as shown in fig. 15) was made to determine the best sampling location. Sampling areas were located along one side of the pile at the top, middle and bottom. The three were matched according to date, pile number and position in the barn.

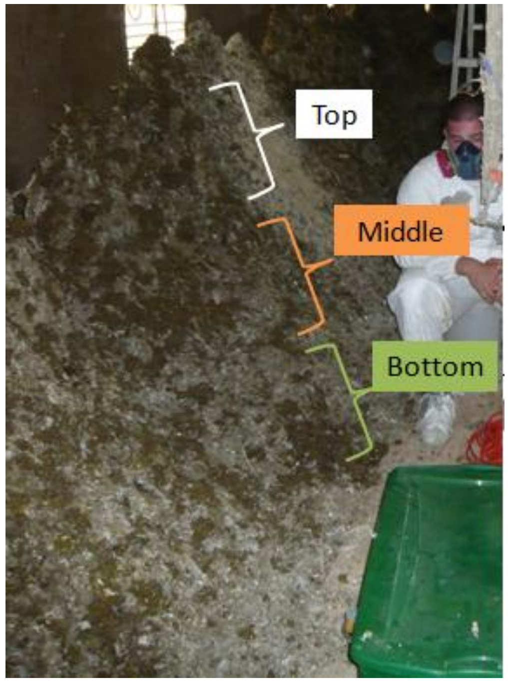

Figure 15. A picture illustrating the approximate location of DFC samples on the pile.

Measurements taken from the top of the piles proved to be the most variable with a standard deviation of 131 ppm for NH_3 concentrations, whereas the middle and bottom locations with the same number of samples had standard deviations of 38 and 28 ppm, respectively. It is important to note that the average NH_3 concentration for the top location was the highest among the three, and average NH_3 concentration for the bottom of the pile was the lowest (fig. 16). The combined average for all three locations is similar to that of the middle location. For this reason the middle samples were considered representative of the overall pile profile.

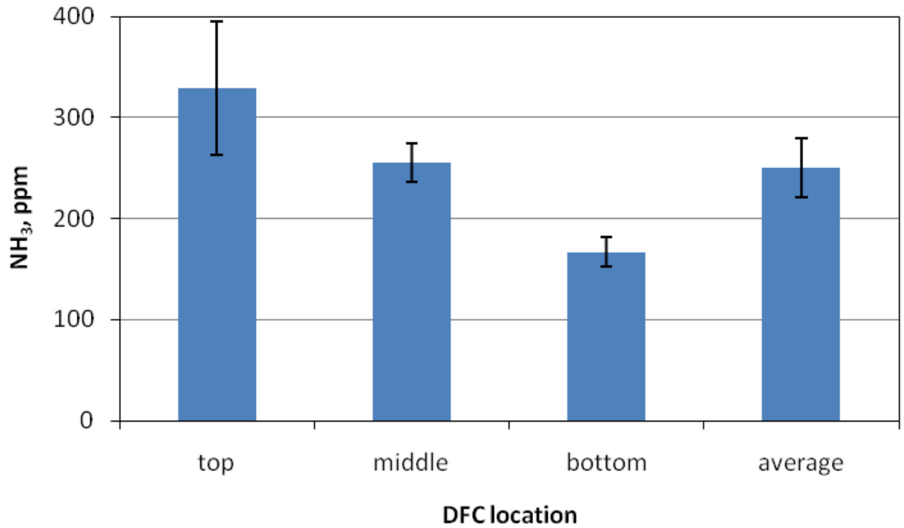

Figure 16. Average NH_3 concentrations from any pile's profile (top to bottom). n = 4 per location

Comparison of DFC and MAEMU

The estimation of gas ER with the DFC was compared to the MAEMU during the same time periods. Considering that manure scraping occurred multiple times a day and gaseous emissions would vary with time, samples of the same approximate locations were taken multiple times on the North-South cross-section in random order. In this way the fresh manure being scraped influenced all locations similarly. Furthermore, the variability in gas concentrations over time can be documented to obtain a more representative ER comparison between the DFC and the MAEMU.

The NH_3 ER values obtained with the DFC were 8% to 16% of those obtained with the MAEMU. This preliminary outcome suggests that the majority of NH_3 emissions of the high-rise layer barn came from somewhere other than the manure piles (fig. 17); which contradicts the MAEMU data that show drastic decrease in NH_3 concentration and thus ER once the manure is removed from the barn. Although fresh manure existed in the cage and dropping board areas, it would likely not account for the large disparity of the two measurement methods. One possible cause for the difference might have been the different air turbulence inside the DFC *vs.* the open manure surface influenced by the manure-drying mixing fans which could have changed the boundary layer conditions and thus NH_3 emission. In addition, the time of manure exposure to air and thus its condition also vary, which would affect the NH_3 emission. Therefore, it is highly possible that the relative short-term measurement of a small manure surface area did not fully represent the conditions of the manure in the barn as monitored by the MAEMU. Finally, effective manure surface area may have been underestimated since the pile profile measurements do not account for the manure's porosity.

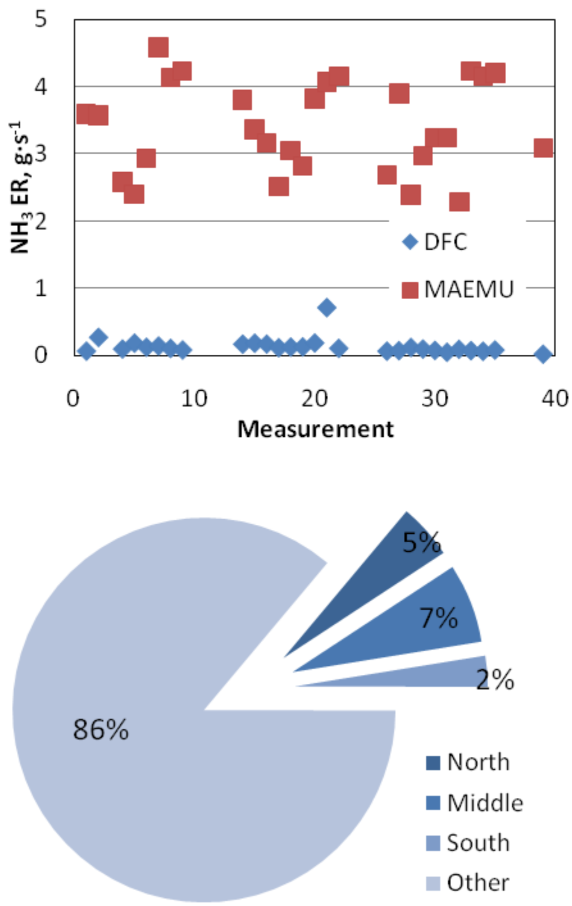

Figure 17. NH_3 ER measurements from the DFC and MAEMU, where each point represents the average for one trial. And percentage of NH_3 emissions from the manure piles, measured with the DFC relative to the entire-barn emission as measured by the MAEMU. n = 37

The CO_2 ER obtained with the DFC was less than 1 to 4% that of the MAEMU, suggesting that most of the CO_2 generation was not from the manure decomposition, but from the bird respiration. This outcome was in general agreement with the report by Pedersen et al. (2008), which suggested adding 10% to the CO_2 produced by respiration to account for manure CO_2 generation. Assuming the emissions determined by the MAEMU represents 100% of the CO_2 emissions and the ones determined by the DFC represent the CO_2 produced by the manure, then the manure is responsible for only 1% of emissions (fig. 18). This was considerably lower than what was described by Pedersen et al. (2008).

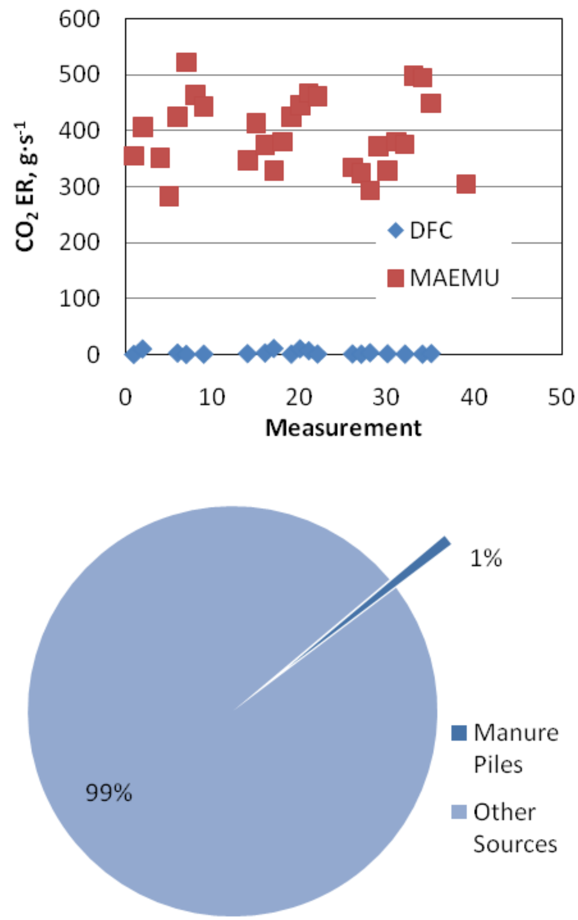

Figure 18. CO_2 ER measurements from the DFC and MAEMU, where each point represents the average for one trial. And percentage of CO_2 emissions from the manure piles, measured with the DFC relative to the entire-barn emission as measured by the MAEMU. n= 37

Dietary Treatment Comparison

Out of the three dietary treatments, the preliminary data showed no significant difference in the NH_3 ER between the DDGS and control treatments (P = 0.600 for winter, P = 0.2669 for spring & P = 0.49 for summer). However, the overall average reduction in emissions was 14% for all three seasons, which is comparable to the 20% reduction in emissions observed by the MAEMU during the same sampling days. More extensive emission measurements with the DFC may have resulted in marked differences between the treatments. Figure 19 shows the difference in emissions between the two treatments.

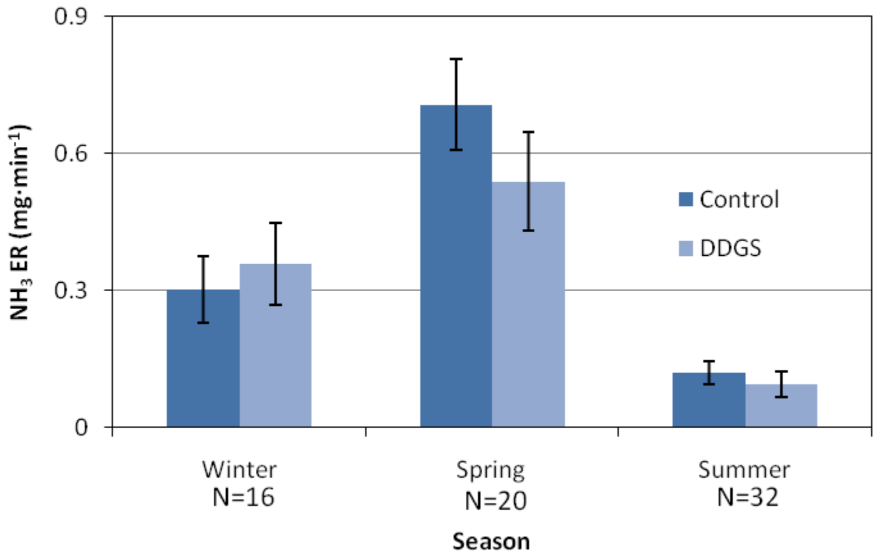

Figure 19. Average NH_3 emission rates for DDGS and control diet manure measured with DFC. n = 8 per treatment during winter, n = 10 per treatment during spring, and n = 16 per treatment during summer.

On the other hand, the ER was significantly lower from the EcoCal™ treatment compared to the control (P <0.001) for the 24 measurements during 3 days in the winter period and the 8 measurements during 3 days in the summer period (fig. 20). The percentage reduction in NH_3 emission using the DFC were 61% and 60% for the summer and winter data, respectively, which is reasonably close to the observed reduction of 54% measured by the MAEMU for the same days sampled by the DFC.

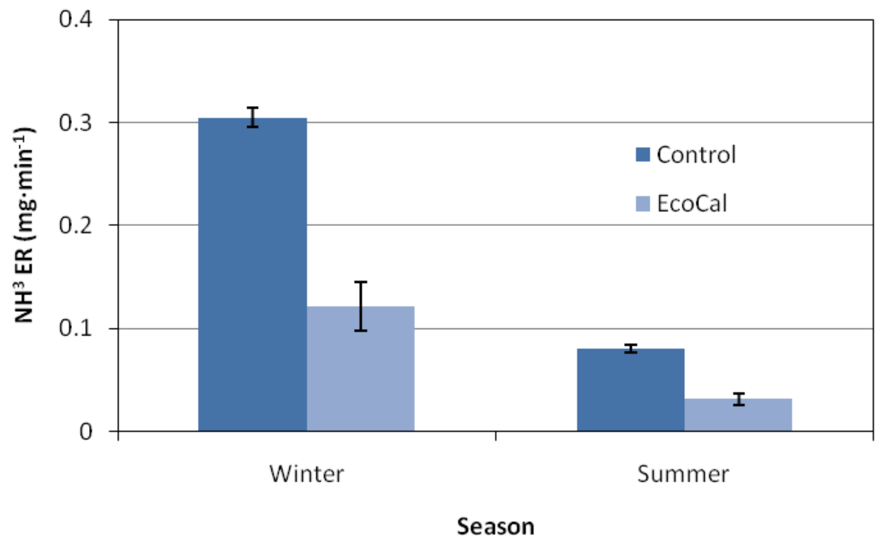

Figure 20. Average NH_3 emission rates for EcoCal^{TM} and control diet manure measured with DFC. n = 12 per treatment during winter, and n = 4 per treatment during summer.

Conclusions

A portable dynamic flux chamber (DFC) system has been developed for measuring gaseous (NH_3, CO_2) emissions from poultry manure surface. Given that the north-south cross-section was the only set of measurements that resulted in a significant difference in NH_3 concentration, the sampling scheme to determine emissions had to include all three locations. Preliminary manure NH_3 emissions measured with DFC were only 8% to 16% of the barn emissions measured with MAEMU. On the other hand, the potential for correction factors exists, such as the effect of air velocity and different air exchange rates on emissions could be considered. It has been observed that seasonal ventilation rates in animal buildings seem to compensate for seasonal NH_3 concentrations and result in a fairly constant NH_3 emission rate, although the relatively short-term measurement of NH_3 emission flux with DFC increases with air exchange rate. Also, the DFC *vs.* MAEMU discrepancy may be determined and adjusted by developing an offset value to match DFC NH_3 emissions to the

MAEMUs depending on the season. Furthermore, reduction in NH_3 emissions by the treatment (EcoCal^{TM}) diet as compared to the control diet was 60% based on the intermittent DFC measurements in winter and spring, which was comparable to the 54% reduction measured with the MAEMU. However, measured reductions from the DDGS treatment diet were not as conclusive.

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References

Bernal, M. P., J. M. Lopez-Real, and K. M. Scott. 1993. Application of natural zeolite for the reduction of ammonia emissions during the composting of organic wastes in a laboratory composting simulator. *Bioresource Technology*. 43:35–39.

Boriack, C., R. E. Lacey, S. Mukhtar, A. Mutlu, S. C. Capereda, B. W. Shaw and C. B. Parnell. 2005 Adsorption kinetics of ammonia on a dynamic isolation flux chamber. ASABE paper No. 054039. St. Joseph, Mich.: ASABE.

Brewer, S. K. and T.A. Costello. 1999. In situ measurement of ammonia volatilization from broiler litter using an enclosed air chamber. *Transactions of the ASAE.* Vol 42(5): 1415-1422.

Burns, R. T., H. Xin, H. Li, S. Hoff, L. B. Moody, R. Gates, D. Overhults, and J. Earnest. 2006. Monitoring system design for the southeastern broiler gaseous and particulate matter air emissions monitoring project. *Proceedings of the Air and Waste Management Association Air Quality Monitoring and Methodologies Conference.*

Cai, L., J. A. Koziel, Y. Liang, A. T. Nguyen, and H. Xin. 2007. Evaluation of zeolite for control of odorants emissions from simulated poultry manure storage. *Environmental Quality*. 36:184-193.

Carlile, F. S. 1984. Ammonia in poultry houses: A literature review. *World's Poultry Science* 40: 99 – 113.

Jacobson, L. D., B. P. Hetchler, V. J. Johnson, R. E. Nicolai and D. R. Schmidt. 2005. Seasonal variations in NH_3 and PM_{10} emissions from pig and poultry buildings from a multi-state project. In Proc. *Symposium on the State of the Science of Animal Manure and Waste Management.* San Antonio, Texas: ASABE.

Jacobson, L. D., J. R. Bicudo, D. R. Schmidt, S. Wood-Gay, R. S. Gates and S. J. Hoff. Air Emissions from animal production facilities. ISAH 2003, Mexico.

Kithome, M., J. W. Paul, and A. A. Bomke. 1999. Reducing nitrogen losses during simulated composting of poultry manure using adsorbents or chemical amendments. *Environmental Quality*. 28:194–201.

Koziel, J. A., D. B. Parker, B. H. Baek, K.J. Bush, M. Rhoades and Z. Pershbacher-Buser. 2005.Ammonia and hydrogen sulfide flux from beef cattle pens: Implications for air quality measurement methodologies and evaluation of emission controls. In Proc. *7th International Symposium*. Paper No.701P0205. Beijing, China: ASABE.

Liang, Y., H. Xin, E. F. Wheeler, R. S. Gates, H. Li, J. S. Zajaczkowski, P. Topper, K. D. Casey, B. R. Behrends, D. J. Burnhan and F. J. Zajaczkowski. 2005. Ammonia emissions from U.S. laying hen houses in Iowa and Pennsylvania. Transactions of ASAE Vol 48(5): 19927-1941. St. Joseph, Mich.: ASABE.

Li H., H. Xin, R. T. Burns, S. J. Hoff, J. D Harmon, L. D. Harmon, L. D. Jacobson, S. Noll, J. A. Koziel. 2008a. Ammonia and PM emissions from a tom turkey barn in Iowa. ASABE paper No. 084425. St. Joseph, Mich.: ASABE.

Li, H., H. Xin, R. T. Burns, S. A. Roberts, and K. Bregendahl. 2008b. Effects of dietary modification on laying hens in high rise houses: Part I – emission of ammonia, hydrogen sulfide and carbon dioxide. ASABE paper No. 701P0408. St. Joseph, Mich.: ASABE.

Li, H., H. Xin, Y. Liang, and R. T. Burns, 2008c. Reduction of ammonia emissions from stored laying hen manure through topical application of zeolite, Al^{+} Clear, Ferix-3, or poultry litter treatment. *Applied Poultry Research*. 17(4): 421 – 431.

Liu, Z., L. Wang and D. B. Beasley, E. O. Oviedo. 2007. Modeling ammonia emissions from broiler litter with a dynamic flow-through chamber system. ASABE paper No. 074090. St. Joseph, Mich.: ASABE.

Liu, Z., L. Wang and D.B. Beasley. 2008. Comparison of three techniques for determining ammonia emission fluxes from broiler litter. *Transactions of the ASAE.* Vol. 51(5): 1783-1790.

LumaSense Technologies. 2007. Photoacoustic Field Gas-Monitor – INNOVA 1412. Santa Clara, CA: LumaSense Technologies Inc.

Mumpton, F. A., and P. H. Fishman. 1977. The application of natural zeolites in animal science and aquaculture. *Animal Science*. 45:1188–1203.

National Academy of Science. 2003. *Air emissions from animal feeding operations current knowledge, future needs.* Washington D.C.: The National Academy Press.

NRC. 1994. *Nutrient Requirements of Poultry.* 9th rev. ed. Natl. Acad. Press, Washington DC.

Pedersen, S., V. Banes-Vidal, H. Joergensen, A. Chwalibog, A. Haeussermann, M. J. W. Heetkamp and A. J. A. Aarnink. 2008. Carbon dioxide production in animal houses: A literature review. Agricultural Engineering International: CIGR Ejournal. Manuscript BC 08 008, Vol. X.

Ramsey F. L. and D. W. Shafer. 2002. *The statistical sleuth: a course in methods of data analysis*. 2nd ed. Pacific Grove, CA: Duxbury Press.

Roberts, S. A., H. Li, H. Xin, R. T. Burns, and K. Bregendahl. 2008. Effects of dietary modifications on laying hens in high rise houses: Part II – hen production performance. ASABE paper No. 701P0408. St. Joseph, Mich.: ASABE.

Roberts, S. A., H. Xin, B. J. Kerr, J. R. Russell, K. Bregendahl. 2007. Effects of dietary fiber and reduced crude protein on ammonia emission from laying-hen manure. *Poult Sci* 86:1625-1632l.

Shah, S. B., G. L. Grabow and P. W. Westerman. 2006. Ammonia adsorption in five types of flexible tubing materials. *Applied Engineering in Agriculture.* Vol. 22(6): 919-923.

van Breemen, N., P.A. Burrough, E.J. Velthorst, H. F. van Dobben, T. de Wit, T. B. Ridder and H. F. R. Reijnders. 1982. Soil acidification from atmospheric ammonium sulphate in forest canopy throughfall. *Nature*. Vol. 299.

Waldroup, P. W., Z. Wang, C. Coto, S. Cerrate and F. Yan. 2007. Development of a standardized nutrient matrix for corn distillers dried grains with solubles. *International Journal of Poultry Science. Vol* 6(7): 478-483

Zhao, L. 2007. Understanding air emissions from animal feeding operations. AEX-721-07. The Ohio State University.

Chapter 4: General Conclusions

Conclusions

This thesis research was conducted with the purpose of developing and evaluating a portable dynamic flux chamber (DFC) system for measuring gaseous (NH_3 and CO_2) emissions from poultry manure surface. The research was carried on to fulfill two objectives: (1) to assess the impact of operational parameters on the performance of the DFC and (2) to validate the 'in situ' performance of the DFC by comparing it to a 'golden standard' system (MAEMU) while assessing NH_3 and CO_2 emissions and dietary effects for high-rise laying hen houses.

The first objective was accomplished by evaluating the air exchange rate expressed in air changes per hour (20, 39, 58 and 78 ACH) and the air turbulence or velocity over the manure surface resulting different air inlet angles (0 *vs.* 45 degree from the horizontal plane) into the DFC. Laboratory tests were performed with laying-hen manure, and the following results were drawn:

- NH_3 and CO_2 emissions were observed to increase with increasing air exchange rate and air velocities inside the DFC.
- The best fit model for CO_2 was a quadratic equation, which hints that emission may be approaching to a maximum regardless of the flow rate. On the other hand NH_3 seemed to increase with air exchange rate in a linear fashion, indicating that fresh air flow rate is a limiting factor for nitrogen decomposition in the manure for the studied flow rates;

- There was evidence of increased gaseous emissions (NH_3 and CO_2) with air velocity over the manure surface at 39 ACH (0 *vs.* 0.07 $m.s^{-1}$), while no significant difference was observed at 78 ACH (0.126 *vs.* 0.152 $m.s^{-1}$).

The second objective was achieved by performing several site visits (over summer and winter seasons) to a farm where the MAEMU system was installed to continuously monitor NH_3 emissions from three high-rise laying hen houses. The DFC was used to measure the emissions in the lower story (manure storage area) of each barn in 9 different locations. Measurements ware taken in two different barns (both being monitored by the MAEMU), where hens in the barn were fed the control (regular layer hen diet) diet and hens in the other were fed the treatment (EcoCal™) diet. The study revealed the following:

- Preliminary manure NH_3 emissions measured with the DFC were only 8 % to 16 % of the barn emissions measured with MAEMU.
- In addition, CO_2 emissions from manure as measured by the DFC appear to account for only 1% of the total emissions measured with the MAEMU.
- Reduction in NH_3 emissions by the treatment (EcoCal™) diet as compared to the control diet was 60% based on the intermittent DFC measurements in winter and spring, which is comparable to the reduction observed with the MAEMU for the same days. However, the NH_3 reduction was considerably higher than the 23.2% observed in similar studies with the MAEMU over a 6 month period. The difference was presumably attributed to the seasonal variation in the efficacy of NH_3 reduction by the diet.
- On the other hand, measured reductions from the DDGS treatment diet were not as conclusive.

Recommendations

Sampling

As a result of this investigation when determining gaseous emissions with a dynamic flux chamber type system the following recommendations were proposed:

- Maintain a high flow rate through the chamber. Higher air flow rates resulted in the best estimation of gaseous emissions. In addition, in previous research emissions did not increase with air flow rate when it was at 5 air changes per minute, thus, maintaining an air flow rate at a level where it is no longer a factor in the emission calculation would reduce the error.
- Use a filter system. Filtering the incoming air to the system would ensure that there is little or no residual gas from previous measurements affecting the trials. Furthermore, background concentrations (incoming air) before each trial are necessary to accurately determine gaseous emissions.
- Select an adequate sampling scheme. Variation in the emission source properties within the same facility may vary significantly, thus, selecting a representative sampling scheme would result in the determination of accurate gaseous emissions.
- Determine emission source surface area thoroughly. The surface area of the emission source is a key part of the emission calculation.

Future work

As a result of this investigation it appeared that the two major factors that affected gaseous emission estimation using a dynamic flux chambers are (1) air flow rate applied to the chamber, and (2) air velocity inside the chamber. Thus, having a flux chamber design that allows the study of the effects of both in a broad range would facilitate further research. Figure 1 shows a sketch of a possible flux chamber design that fits both parameters. The design should include variable speed mixing fans to change air speeds as necessary, and in front of the mixing fans have wire mesh to normalize the air velocity through the entire chamber. Also, the design should have controlled flow up to 5 air changes per minute through multiple air inlets to allow good air mixing inside the chamber. A multiple sampling port composite with a static mixer may allow a more certain and consistent concentration measurement. In addition, a ring surrounding the chamber to seal the inside environment would be helpful to minimize artifact caused by the outside environment. Finally, a larger surface area would result in a more representative sample.

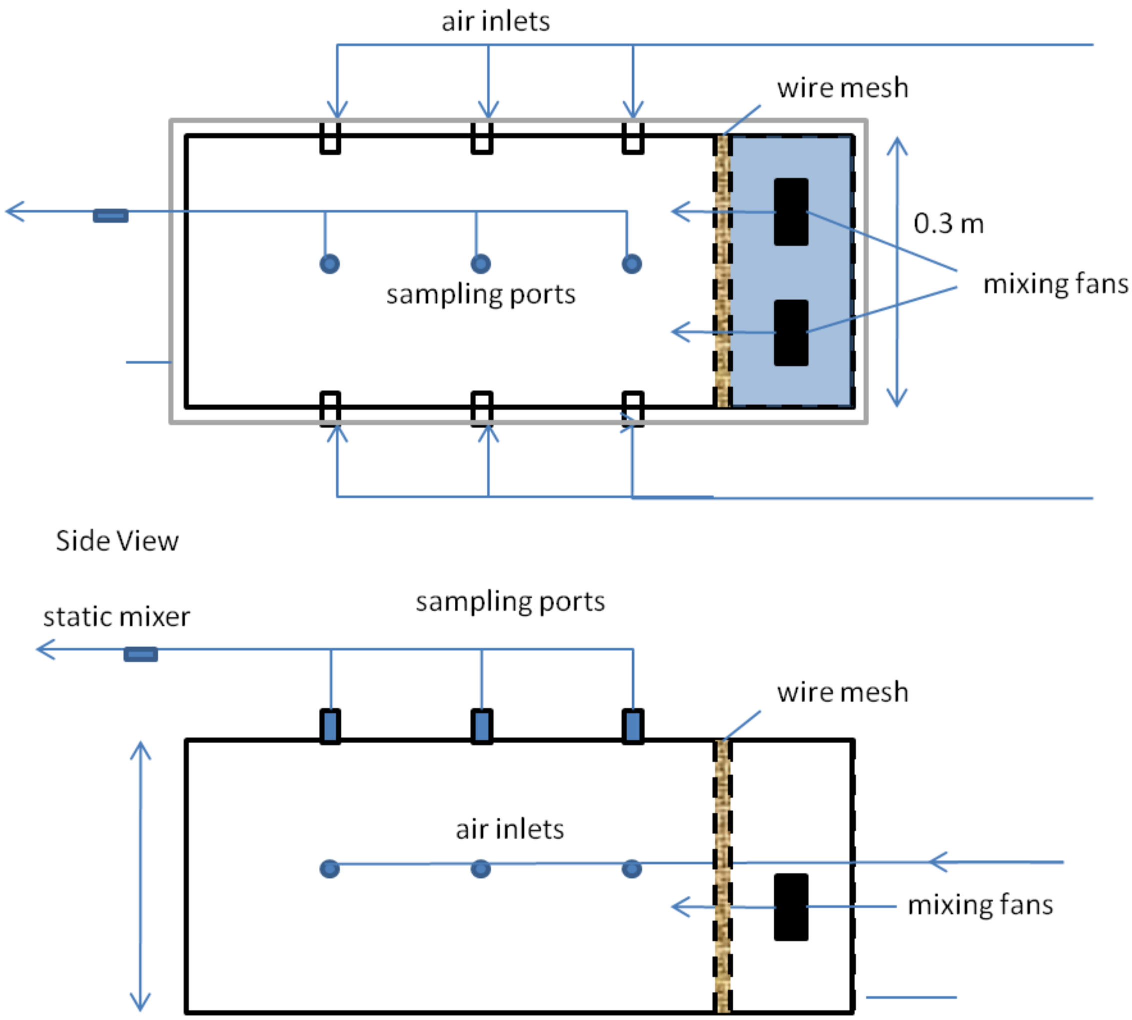

Figure 1. Sketch of a flux chamber that allows variable air velocity and air flow rate. The lines with the arrows show the direction of the air.