Protocols for Monitoring Ammonia, Methane, and Nitrous Oxide from Animal Housing and Manure Management Systems as Part of the GHG Quantification Project

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Overview

The Greenhouse Gas (GHG) Research Network is measuring the impact of management practices on nitrous oxide and methane emissions, and soil carbon sequestration. Data will be used by researchers to improve outcome estimates, including through the advancement of models and tools. The GHG Research Network is organized into four sub-teams that target GHG measurements in different agricultural sectors, including Land Emissions, Enteric Methane, Animal Housing and Manure Storage, and Tall Towers.

Each of these four sub-teams has developed GHG measurement protocols to provide technical information on the methods used to measure GHGs and applicable data processing procedures. Protocols outline the method used by the Agricultural Research Service (ARS) for this specific project. Other efforts may use different protocols. The protocols are published to promote dialogue and feedback, and to serve as a reference for other research, when applicable. Protocols will be updated as needed. Protocols will be updated as needed. This document is the protocol for the Animal Housing and Manure Management subteam.

The 2022 EPA GHG inventory reported that methane (CH_4) and nitrous oxide (N_2O) emissions represented 11% and 6%, respectively, of total CO_2eq generated in the US. Livestock operations contribute to the US GHG budget through emissions of CH_4, N_2O and ammonia (NH_3; indirect source of N_2O). Enteric fermentation is the largest anthropogenic source of CH_4 emissions accounting for 27.4% of total CH_4 emissions, while manure management represents 9% of total CH_4 emissions. About 4% of total US N_2O emissions are generated from manure management. Gaseous emissions from livestock production are formed by a complex set of microbial, physical, and chemical processes that occur within the animal and the manure storage/processing system. Appreciable spatial and temporal variation can occur in gaseous emissions because of differences in the animals, the diets, manure storage/handling systems, and the environment (NRC, 2003; Powers et al., 2014; NASEM, 2016). It is imperative to increase GHG emission measurements from the housing and manure management components of livestock production systems to improve understanding of the processes controlling gaseous emissions and evaluate mitigation strategies effective at reducing these emissions.

There are relatively few published data related to GHG emissions from livestock facilities and even fewer studies documenting the effectiveness of mitigation practices on commercial farms. Monitoring livestock facilities is expensive, time consuming, and requires considerable expertise to obtain accurate and representative data. Models to estimate on-farm emissions will continue to be used from farm to inventory scale. Improvements to current models based on monitoring data will enable more accurate emissions estimates and better evaluate the overall changes in emissions with adoption of management practices.

The goal of the IRA Livestock Housing and Manure Management effort is to improve our understanding of these emissions, the factors that control them, and build a dataset that will enable improvement of models, assessment of mitigation strategies, and improved inventories. Work will mainly be conducted on commercial livestock operations and will follow standard monitoring protocols described below.

Measurement Methods

Emissions of GHG and NH_3 on livestock operations come from the management of manure in both housing and a variety of manure handling and storage areas, as well as from enteric methane produced by ruminants in the housing. Measurement of these emissions vary depending on housing type and manure management system. There are three main categories of housing: confinement structures that are totally enclosed with full-time mechanical ventilation (tunnel or cross ventilation), partially enclosed structures with or without mechanical ventilation, or paved/unpaved open lots. Manure management systems vary widely but typically consist of manure stored as a solid in some sort of stack/pile that is either static or turned (composted) or as a liquid stored in earthen basins, tanks (enclosed and open), or a variety of other structures. Measurement methods will differ for fully closed vs open sources.

<u>Fully Enclosed Structures with Mechanical Ventilation</u>**:** For an enclosed structure where air flow is maintained via a mechanical system, emissions can be estimated by determining the concentration of gasses in the exhaust air along with the ventilation air flow rate, temperature, relative humidity and barometric pressure using the equation below.

$$ER_G = \sum_{e=1}^{3} Q_e \left([G]_e - \frac{\rho_e}{\rho_i}[G]_i \right) \times 10^{-6} \times \frac{w_m}{V_m} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}}$$

ER_G = gaseous emission rate of the house (g hr^{-1} $house^{-1}$)
Q_e = ventilation rate of the portion of the house at location “e” (SW1, SW3 or TE) at field temperature and barometric pressure (m^3 hr^{-1} $house^{-1}$)
$[G]_i$ = gaseous concentration of incoming house ventilation air, parts per million by volume (ppm_v)
$[G]_e$ = gaseous concentration of exhaust house ventilation air of the portion of the house at location “e” (ppm_v)
w_m = molar weight of air pollutants, g $mole^{-1}$
V_m = molar volume of gas at standard temperature (0°C) and pressure (1 atmosphere) (STP), 0.022414 m^3 $mole^{-1}$
T_{std} = standard temperature, 273.15 K
T_a = absolute house temperature, (°C+273.15) K
P_{std} = standard barometric pressure, 101.325 kPa
P_a = atmospheric barometric pressure for the site elevation, kPa
ρ_e = air density at exhaust fan location “e”, kg dry air m^{-3} moist air
ρ_i = air density at outside conditions, kg dry air m^{-3} moist air

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Measurement of gasses within the enclosed structure (open path instrument) or at the ventilation fans (point measurements) should be done continuously over the monitoring period at intervals between 30- and 60-min. Background concentrations should also be monitored to determine ambient concentration of gasses entering the building on the same time interval. Monitoring periods should cover either the variability during a production cycle or over the course of a year to obtain an accurate production cycle/annual emission rate. In the current project, gasses will be measured using photoacoustic multigas analyzers, open path tunable diode lasers, or cavity ring down spectroscopy (G2508 or G2509, Picarro Inc.).

Flow rate is estimated by continuously measuring fan operational status and building static pressure, applying field-tested fan performance curves (FANS), and by directly measuring the air flow from selected fans using anemometers. FANS calibration should be done every 6 to 12 months depending on the cleaning schedule of the ventilation system.

Table 1. Parameters continuously monitored in enclosed system

Parameter	**Units**	**Frequency**
gas concentration	ppm	30 to 60 min intervals
temperature	°C	Every minute
Barometric pressure	kPa	Every minute
Relative humidity	%	Every minute
Fan on/off time		As occurs
Static Pressure	In H_2O	Every second

<u>Open-Source Area Measurements</u>: Emissions from on-farm sources that are not enclosed (ie. open lots, lagoons, open tanks, etc.), can be estimated by measuring the concentration of gasses along with wind flow at the site. Dispersion models can determine the flux rate of a gas based on downwind gas concentrations or predict downwind gas concentrations when the flux rate is known. They are based on a mathematical description of the relationship between a gas source and a downwind receptor or point using assumptions about turbulent flow (Wilson et al., 2001). The backward Lagrangian Stochastic (bLS) model, which has been frequently used in research studies, estimates flux of a gas by modeling the trajectories of thousands of gas particles backward to the emitting source as in Fig. 1 (Flesch et al., 1995, 2005). For a detailed description of the backward Lagrangian stochastic (bLS) technique, see Flesch et al. (2005a,b; 2007). The bLS model requires a small number of inputs, has been validated for estimating fluxes with gas release experiments, and has been shown to estimate emissions within 15% of actual emissions (Flesch et al., 1995, 2004; McGinn et al., 2009; Gao et al., 2010; Ro et al., 2013). This technique has been successfully applied to a variety of livestock housing and manure management systems (McGinn et al., 2006; Flesch et al., 2007; van Haarlem et al., 2008; Todd et al., 2008, 2014; Arndt, 2018; Leytem et al. 2011, 2013, 2017, 2018).

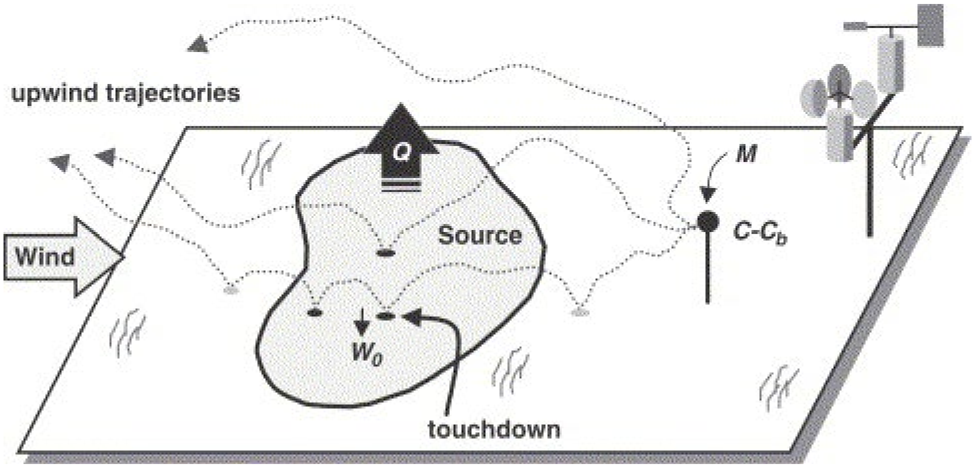

Fig. 1. The inverse-dispersion technique for estimating emission rate (Q). Concentration rise above background (C-Cb) is measured at M. The ratio (C/Q)sim is calculated with a dispersion model. In a bLS model, trajectories are calculated upwind of M, and (C/Q)sim is given by trajectory "touchdowns" inside the source (w0 is the vertical velocity at touchdown).

Concentration of gasses upwind and downwind of the source area can be determined via a variety of methods. In the IRA project, gas concentrations will be monitored using open path Fourier transform spectroscopy (CH_4, N_2O, NH_3) or tunable diode lasers (NH_3, CH_4). Both instruments have the advantage of determining a path-integrated concentration, which can provide an average across source areas that may have some spatial variability in emissions. Concentration data are collected at 5 min intervals and processed to produce 15-min average mixing-ratio concentrations at the source areas.

The wind environment will be described by simple Monin-Obukhov similarity theory (MOST) relationships defined by u*, L, z0, and β, as provided by 3-dimensional sonic anemometers (RM Young Model 81000 ultrasonic anemometer, Traverse City, MI), where u* is the friction velocity, L is the Obukhov stability length, z0 is the surface roughness length, and β is wind direction. Flesch et al. (2004) details how these parameters are calculated from a sonic anemometer. A meteorological station will be located at each source to record barometric pressure, air temperature, relative humidity and solar radiation during the experimental period. WindTrax 2.0 will be used to determine emissions rates from open sources. WindTrax is a free software tool for simulating short-range atmospheric dispersion (for horizontal distances within about 1 km of the source). It has been designed as an easy-to-use graphical interface for assessment of turbulent transport on the micro-meteorological scale using Lagrangian stochastic particle models. For software download, documentation, and publication references, go to thunderbeachscientific.com.

Good emission estimates depend on using data that violate the ***LEAST*** assumptions (i.e., low winds, extreme stabilities, wind profile errors). Data will be filtered by removing periods when $u^* \leq 0.10$ m s^{-1} (low wind conditions), $|L| \leq$ 5 m (strongly stable or unstable atmosphere), and $z0 \geq 1$ m (associated with errors in wind profile; Ro et al., 2013; Flesch et al., 2014). Due to the location of the concentration sensors and other source areas on a farm, for some wind directions, measurements of downwind concentrations may not sample enough of the farm plume, which can lead to uncertainty in emission estimates (Flesch et al., 2005). Additionally, there could be cross-contamination due to emissions from other source areas on the farm. Therefore, data will also be filtered based on wind direction to ensure measurements are made within the plume and avoid cross contamination from other sources.

Table 2. Parameters continuously monitored in open system

Parameter	Units	Frequency
Gas concentration	ppm	5 min
Temperature	°C	15 min
Barometric pressure	kPa	15 min
Relative humidity	%	15 min
Solar radiation	Watts/m^2	15 min
Wind statistics (anemometer)		15 min

<u>Mobile Van Measurements</u>**:** Aerodyne Research Inc. will conduct ground measurements using the tracer flux ratio (TFR) method (Lamb et al., 1995; Mønster et al., 2014; Roscioli et al., 2015) with a mini–Aerodyne Mobile Laboratory (Herndon et al., 2005). Mixing ratios of various species are measured every second using Aerodyne single-laser quantum cascade laser spectrometers [CH_4, NH_3, acetylene (C_2H_2), and ethane (C_2H_6)] and a nondispersive infrared LI-6262 gas analyzer (CO_2 and H_2O) from LI-COR Biosciences Inc. (Lincoln, NE). The sample inlet is 2.2 m above ground, on the passenger side, and extends ahead of the vehicle as far as the front bumper. Sample air is drawn through a particle filter from a 1.27 cm outer diameter (O.D.) Teflon tube. After the filter, two flow paths diverge, with 625 standard cubic cm per minute (sccm) splitting out to a LiCor-6262 to measure CO_2, while 9 to 11 standard liters per minute (slpm) are directed to two tunable infrared direct laser spectrometers (TILDAS) in series. A pressure controller placed upstream of the first TILDAS regulates the cell pressure downstream. The typical operating protocols and sampling techniques have been described previously (Herndon et al., 2005). Three TILDAS quantify ammonia NH_3, CH_4 and ethane C_2H_6, as well as other species. A thorough description of the TILDAS instruments is documented elsewhere (Yacovitch et al., 2014), but some brief details of how they were deployed on this project are warranted. The first spectrometer quantifies H_2O-vapor and CH_4 using the rotation-vibration absorption lines between 1300.8 and 1301.7/cm. The second spectrometer quantifies C_2H_6 using the lines at 2996.8/cm. The third spectrometer quantifies NH_3 using the lines at 967 cm^{-1} with a precision <50 pptv in 1 second. An AirMar 200WX anemometer mounted on the sample mast is used to measure wind speed and direction. The position and orientation of the minAML is determined by a Hemisphere GPS model V103. The C_2H_2 and C_2H_6 tracer gases are released using Alicat Flow Controllers (MCR-20). Calibration verification is performed up to 20 standard L/min.

The calculation of emission rates from TFR are described in detail elsewhere (Roscioli et al., 2015). In brief, emission rates using the TFR method are obtained by comparing the plumes (enhancements above background) of tracer gases and CH_4 (or NH_3, N_2O) within multiple driven transects (typically one transect per unique estimate). By controlling the tracer release rate (mm T) and observing enhancements of CH_4 ($\Delta[CH_4]$; Equation 2) and tracer gases ($\Delta[T]$), meteorological conditions (α) no longer factor into determining the emission flow rate ($mm\dot{}CH_4$; Equation 3, (Lamb et al., 1995; Roscioli et al., 2015).

Equation 2. Determination of enhancements of CH_4 ($\Delta[CH_4]$)

$\Delta [CH_4] = \alpha \times \dot{m}_{CH4}$

where,

α = meteorological conditions (mole/mole).

$\dot{m}_{CH4}$ = emission flow rate (standard liters per min)

Equation 3. Determination of emission flow rate ($\dot{m}CH_4$).

$\dot{m}_{CH4} = (\alpha_T / \alpha_{CH4}) \text{ x } (\Delta [T] \text{ x } \dot{m}_T) / \Delta [CH_4])$

where,

α_T = meteorological conditions experienced by the tracer gas (mole/mole).

α_{CH4} = meteorological conditions experienced by the emission (mole/mole).

$\Delta[T]$ = Tracer gases (parts per million).

$\dot{m}_T$ = Tracer release rate (standard liters per minute).

$\Delta[CH_4]$ = Enhancements of CH_4 (parts per million).

Methods used to quantity $\dot{m}CH_4$ include performing linear regressions ("dual-correlation" and "single-correlation"), comparing integrated areas ("dual-area"), or calculating linear combinations ("dual-sum") between the aforementioned species. If a linear regression between C_2H_4 and C_2H_6 indicates correlation (high R^2) and the error in tracer release rate (ratio of expected rate to observed rate) falls in the appropriate range (factor of 0.5 – 2.0), determining the emission requires multiplying the linear fit of CH_4 and C_2H_6 with the C_2H_6 release rate. Similarly, dual area involves using ratios of integrated areas for tracer and CH_4

enhancements instead of slopes. In the absence of dual tracer correlation, a single tracer well-fitted to CH_4 multiplied with that tracer's release rate, dictates the emission rate. In the scenario that each tracer plume only partially overlaps the site-wide emissions, a linear combination of these tracer slopes now allows for direct comparison with the whole-facility CH_4 emission via linear regression. Examples of each method being applied to transects performed by minAML during similar campaigns can be found in Roscioli et al., (2015).

Ancillary Data Collection

List of Data Collected for Housing and Manure Management
Variables in Red are Needed for Mobile Van Measurements

General:
Gasses measured, Emission measurement technique, Date, Daily emission rate

Animal Variables:
Animal category
Breed and Number of animals
AU (animal units), Weight, and Weight gain
Production cycles (ie for swine how long does a cycle last and when did it start and finish)
Milk production and components
Diet composition (feed ingredients) and chemistry (DM, ash, CP, fat, ADF, NDF, starch, lignin, sugar, ME, P, K, Ca, S, Zn, Cu?)
Dry Matter Intake

Housing Variables:
Housing type
Floor type
Type of bedding and Rate of bedding added
Ventilation system and Ventilation rate
Heating/cooling system
Housing RH and temperature
Water use information and cleaning products used in barn or in milking parlor

Manure Storage Variables:
Manure type
Manure management system description
Manure treatment
Manure volume at each stage (under barn, outside etc)
Emptying time and method of removal
Last lagoon/housing cleanout
Manure characteristics (DM, TS, VS, total N, TAN, TC, ash, Bo, pH, P, K, Ca, S, Zn, Cu)

Along with manure characteristics where were the samples collected from (pump out, fresh, etc)
Climate (air temperature, RH, solar radiation, precipitation, wind speed)
Manure pH, temperature

Data Management

Database templates have been developed in Excel to collate data from each site. Data will be uploaded into templates and sent to the database manager (located in Kimberly, ID) quarterly for entry into the larger database. No personal or other identifying information will be included in the database that would enable someone to know the identity of the farm.

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