Appendix F

Western Dairy Air Quality Symposium

Sponsored by
Western States Dairy Producers Trade Association

March 21 – 22, 2006
The Orleans Hotel & Casino
Las Vegas, NV

Western Dairy Air Quality Symposium

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Western States Dairy Producers Trade Association

AGENDA

Tuesday March 21, 2006

11:30 am	**Lunch**
12:00 pm	**Welcome & Introductions**
	Ron Sheffield, University of Idaho
	Research Presentations
	Larry Stap, Western States Dairy Producers Trade Association (Moderator)
12:15 pm	Ray Knighton, USDA, Washington DC
12:30 pm	Nichole Marcillac, Colorado State University, Animal Science
12:45 pm	Ron Sheffield, University of Idaho, Bio & Ag Engineering
1:00 pm	Peter Griffiths, University of Idaho, Chemistry
1:15 pm	Pius Ndegwa, Washington State University, Bio & Ag Engineering
1:30 pm	Gail Bingham, Utah State University, Space Dynamics Lab
1:45 pm	Randy Martin, Utah State University, Civil & Environmental Engineering
2:00 pm	**Break**
2:20 pm	Al Heber, NAEMS Project, Purdue University
2:35 pm	Al Rotz, USDA/ARS, University Park, PA
2:50 pm	Wendy Powers, Iowa State University, Animal Science
3:05 pm	Saqib Mukhtar, Texas A&M University, Bio & Ag Engineering
3:20 pm	Ken Casey, Texas A&M University, Bio & Ag Engineering
3:35 pm	Charlie Krauter, Dave Goorahoo & Matt Beene, California State University-Fresno
3:55 pm	**Break**
4:15 pm	William Salas, Applied Geosolutions, LLC
4:30 pm	Ruihong Zhang, University of California-Davis, Bio & Ag Engineering
4:45 pm	Frank Mitloehner, University of California-Davis, Animal Science
5:00 pm	Peter Green, University of California-Davis, Civil Engineering
5:15 pm	Jeff McGarvey, USDA-ARS Foodborne Contaminants Research Unit, Albany CA
5:30 pm	**A Plan for the West**
	Paul Martin, Western United Dairymen (Moderator)
5:45 pm	**Adjourn** for the evening

Wednesday March 22, 2006

6:30 am	**Breakfast**
7:30 am	**A Plan for the West**
	Joe Harrison, Washington State University (Moderator)
9:30 am	**Group Discussion and Plan of Action**
	Moderators:
	Paul Martin, Western United Dairymen
	Larry Stap, Western States Dairy Producers Trade Association
10:30 am	**Adjourn**
10:30 am	Informal discussion among researchers
11:00 am	*Lunch*

Western Dairy Air Quality Symposium

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Air quality research investments at the Cooperative State Research, Education, and Extension Service

Research Unit:
USDA-CSREES

Contact:
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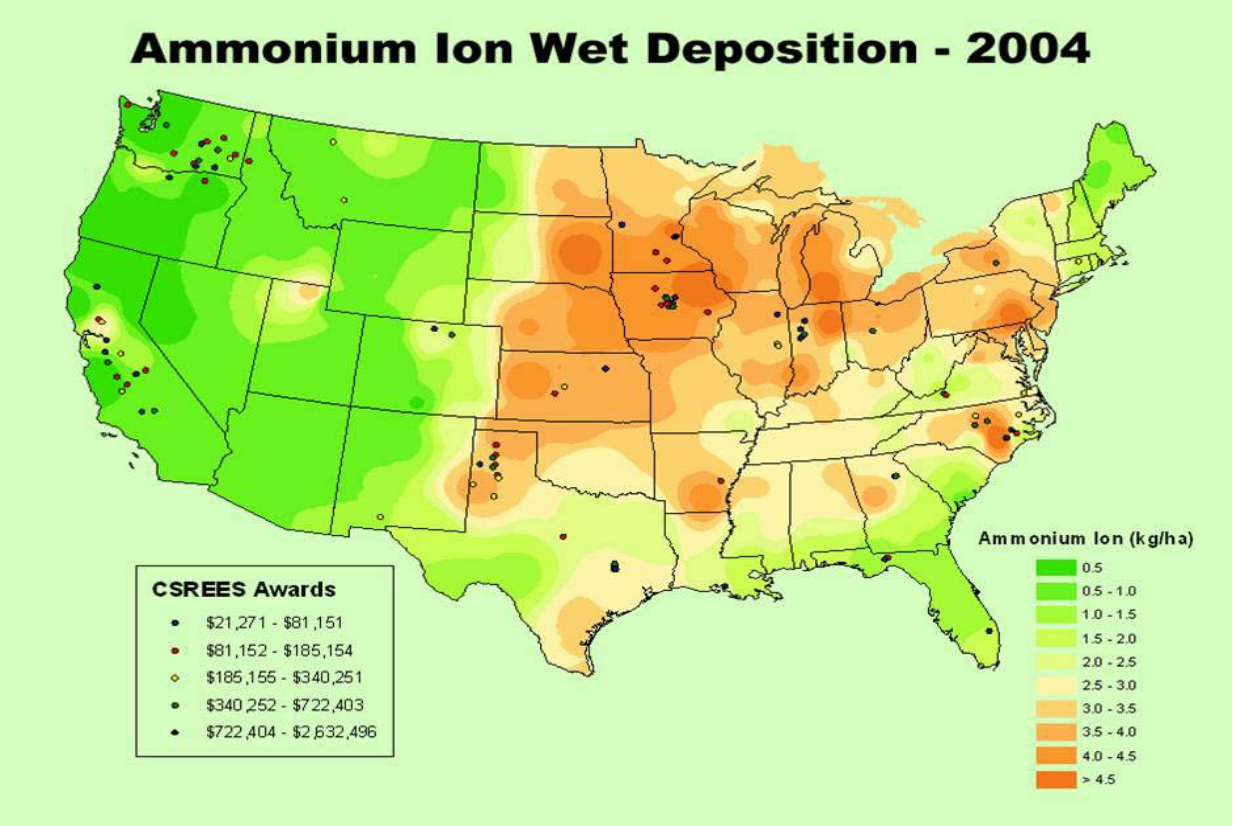
Collaborators:
United States' Universities and Federal Labs

Dates of Research: Active Research

Funding Agencies:
USDA-CSREES

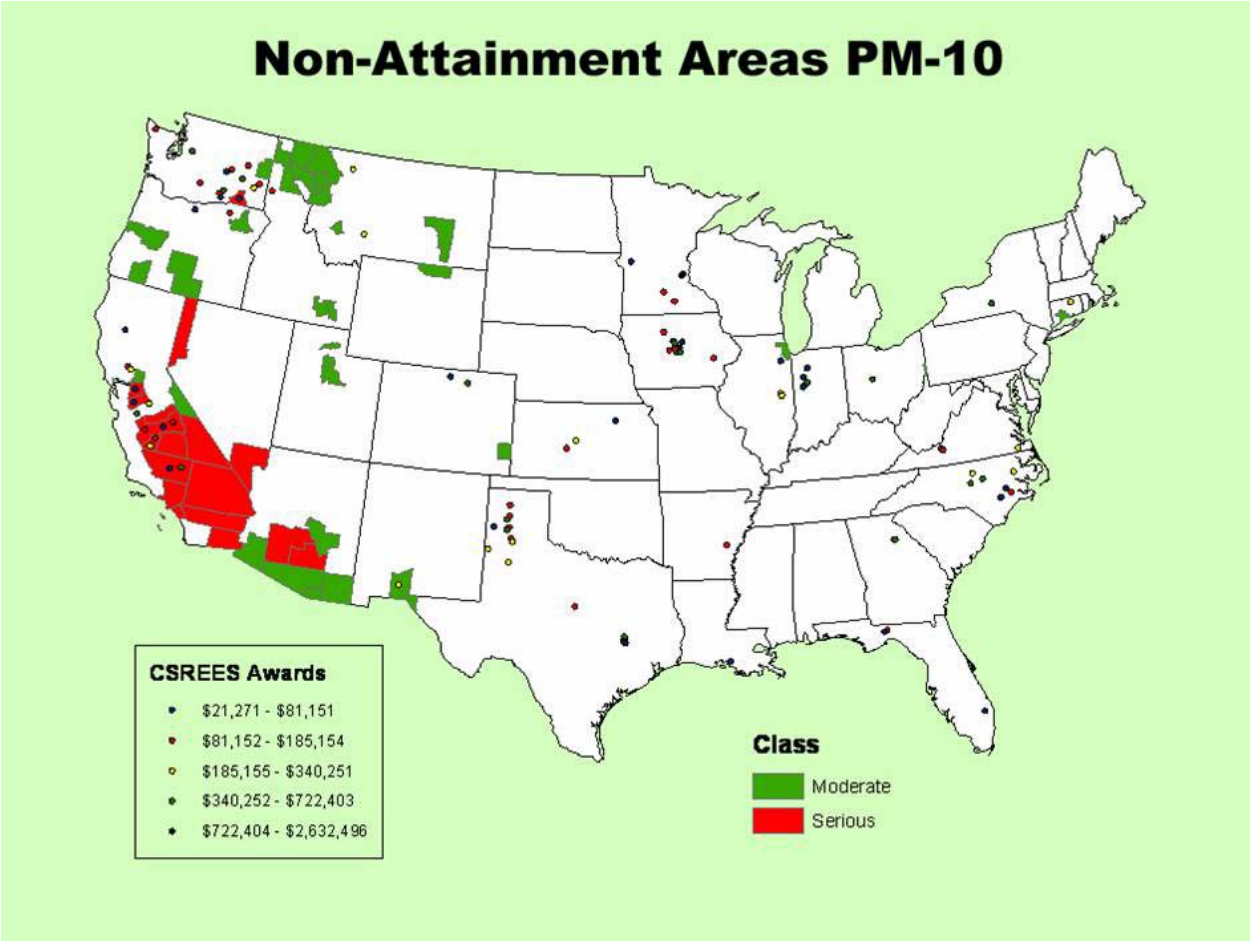
Total Funding: $10,000,000

The Cooperative State Research, Education and Extension Service (CSREES) of USDA provides grants to universities and federal labs to conduct research and extension on a wide range of topics. CSREES provides funding using three mechanisms: formula funds to the land-grant universities, special research grants to



CSREES Research Investments by NH4 Wet Deposition

research institutions, and competitive grants. All three funding mechanisms will be described and quantified. Current air quality research investments of CSREES will be described and a listing provided of projects that relate specifically to dairy. A discussion will be provided of the current request for applications of the National Research Initiative Air Quality program. In addition, the competitive grants and special research grants will be depicted geographically in response to atmospheric deposition of NH4 and non-attainment areas of PM.



CSREES Research Investments by PM Non-Attainment

Process-based modeling of gaseous emissions from dairy farms

Research Unit:
USDA / Agricultural Research Service, University Park, PA

Contact:
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Collaborators:
University of California at Davis
The Pennsylvania State University
National Dairy Environmental Task Force

Dates of Research:
October 2005 – September 2007

Funding Agencies:
USDA / Agricultural Research Service

Total Funding: $200,000

Gaseous emissions to the atmosphere are a growing concern in animal agriculture including dairy farms. Gaseous compounds of most concern include ammonia, hydrogen sulfide, volatile organic compounds, and greenhouse gases such as methane and nitrous oxide. Each of these has different environmental effects. Measuring the loss of these gases from farms is difficult, often inaccurate, and very expensive. Losses are also dependent upon farm management, so large differences can occur among farms. For these reasons, a report from the National Research Council recommended the use of a process-based modeling approach for estimating farm emissions and the effects of management on these emissions. The Dairy Facility Gaseous Emission Model is being developed to meet this need for dairy farms (Figure 1).

The Dairy Facility Gaseous Emission Model will include a process-based simulation of gaseous emissions from housing facilities, manure storages, field applied manure, and grazing animals. These major processes that permit gaseous emissions are simulated through time over many years of weather to obtain long term estimates of maximum and average emissions. The major components of the current model include available feeds, animal intake and manure production, and manure handling. The feeds available and their nutrient contents are provided through user input. Balanced rations are prepared for each animal group on the farm and feed intake is determined to meet their energy and protein requirements. Based upon feed intake, growth, and milk production, the nutrient output in manure is predicted. From this

nutrient excretion, gas emissions are predicted as a function of meteorological conditions and management practices.

The primary objective is to create a relatively simple and easy to use software tool that predicts each of the major gaseous emissions from dairy farms on both a daily and annual basis. The model must use readily available information about the farm yet provide accurate estimations of the formation and loss of the various gasses. This model will be developed in phases with the first phase being the simulation of ammonia emissions. Hydrogen sulfide will be the focus of the second phase, followed by volatile organic compounds, and finally the greenhouse gases. Model development is being done in collaboration with basic research on gas formation and emission from cattle manure conducted at the University of California in Davis, the US Dairy Forage Research Center in Madison, Wisconsin, the Pennsylvania State University, and other institutions. The model will be validated against data gathered over the next two years through the monitoring of five or more dairy facilities throughout the US. This science-based and farm validated tool will then be made widely available for evaluating the gaseous emissions from dairy farms. By simulating various management practices, the tool will be used to evaluate the potential benefits of various technologies and strategies developed for reducing gas emissions.

The process-based algorithm for simulating gas emissions will also be integrated into a whole-farm simulation model to provide a research tool for more extensive evaluation of the interaction between gas emissions and other farm processes including water quality impacts and farm profitability (Figure 2). This farm simulation model will be made available to other researchers and educators working on whole-farm impacts of technologies and strategies used to reduce the environmental impacts of dairy farms.

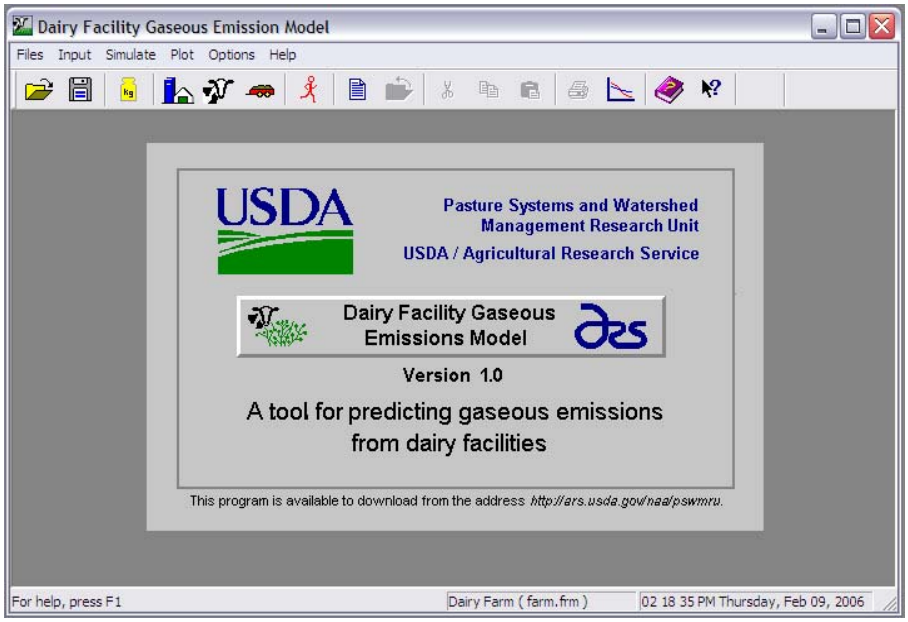

Figure 1. The Dairy Facility Gaseous Emissions Model will provide a Windows based tool for rapid estimation of the gaseous emissions from dairy farms.

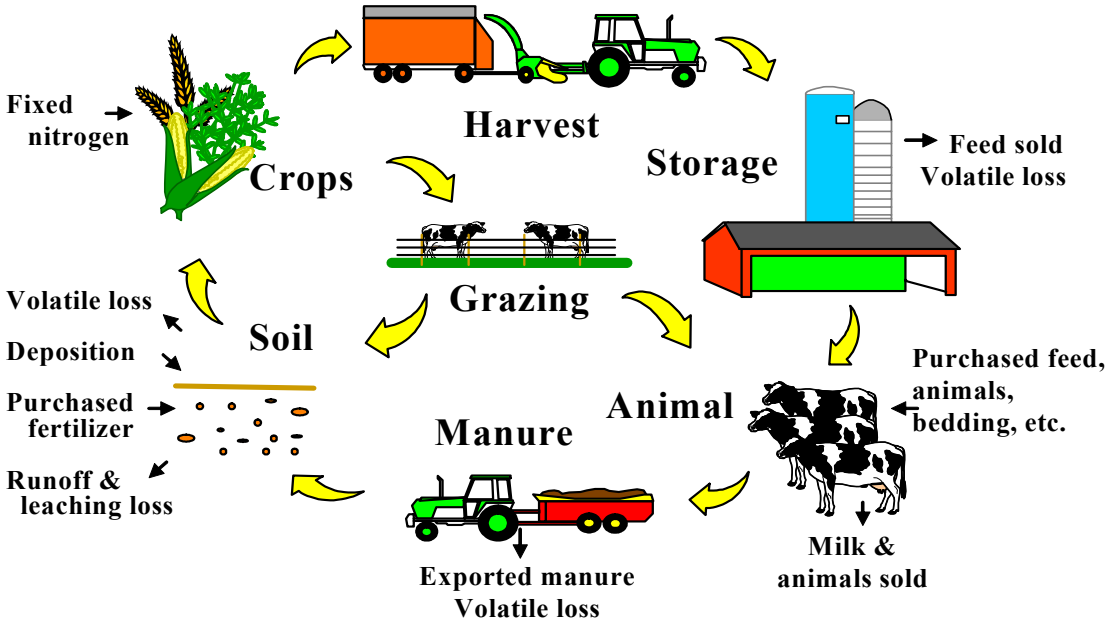

Figure 2. The process-based model of gaseous emissions will be incorporated into a whole-farm simulation model to provide a research tool for studying management effects on gas emissions and their interaction with other farm components including water quality impacts and farm profit.

National Air Emission Monitoring Study (NAEMS)

Research Unit:
Perdue University

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Collaborators:
Rich Grant, Agronomy, Purdue University
Several subcontracting universities

Dates of Research:
Estimated: July 2006 – September 2007

Funding Agencies:
Agric. Air Research Council (John Thorne, Exec. Dir., jthorne@crowell.com)

Total Funding: Approximately $12,500,000 ($5,000,000 for dairy component)

The National Air Emission Monitoring Study (NAEMS) is required by an innovative and voluntary Consent Agreement between the U.S. EPA and the pork, dairy, egg and broiler industries. Livestock producers agreed to collect air emission data, via the NAEMS, in exchange for temporary protection from further government lawsuits and forgiveness of possible past offenses. The specific objectives of the NAEMS are to:

1. Determine whether individual farms are likely to emit particulate matter (PM) and volatile organic compounds (VOCs) in excess of applicable Clean Air Act thresholds.
2. Determine whether individual farms are likely to emit NH_3 and/or H_2S in excess of applicable Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and Emergency Planning and Community Right-to-Know Act (EPCRA) reporting requirements.
3. Form a database with which additional studies of air emissions and effectiveness of control technologies can be compared, and from which emission factors can be developed.

The NAEMS, scheduled to begin in late 2006, will employ continuous monitoring from on-farm instrument shelters to determine emissions from barns, and micrometeorological methods to do the same for dairy corrals, lagoons and manure basins.

At each of one broiler site, three egg production facilites, five swine farms, and six dairies, an on-farm instrumentation shelter (OFIS) will house equipment for

measuring ammonia, hydrogen sulfide, carbon dioxide and VOC concentrations at representative air inlets and outlets, barn airflows, operational processes and environmental variables. A multipoint gas sampling system will draw air sequentially from representative barn locations and deliver selected streams to a manifold from which on-line gas monitors draw subsamples. Mass concentrations of PM_{10} will be measured at one representative exhaust location in each barn using a tapered element oscillating microbalance (TEOM). Sampling of all of these parameters will be conducted for 24 months, with data logged every 60 seconds. Total suspended particulate (TSP) and $PM_{2.5}$ will be measured gravimetrically. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors.

Micrometeorological techniques will be used to estimate emissions of NH_3 and H_2S from a swine manure basin, five swine lagoons, an egg layer lagoon, three dairy lagoons, and two dairy corrals. This approach will use optical remote sensing, both downwind and upwind of the storage or corral, coupled with 3D and 2D wind velocity measurements. The concentrations of NH_3 will be determined using scanning tunable diode laser absorption spectroscopy. Measurements of H_2S and NH_3 will be conducted using UV differential optical absorption spectroscopy. A monitoring team will conduct an 11-day test at each farm each quarter for two years.

As recommended in the National Academy of Science 2003 report, “Air Emissions From Animal Feeding Operations,” measurements will be made during the NAEMS to initiate a process-based consideration of the entire animal production process and its effects on air emissions. This will include measurements or documentation of animal age and weight gain; animal activity; manure handling; feeding, lighting, heating and cooling schedules; fan operation; inside and outside air temperatures and humidity; wind speed and direction; solar radiation; feed and water consumption; manure production and removal schedules; mortalities; animal production schedules; and analyses of total nitrogen in feed, water, and manure. These observations, plus those of parallel studies funded by the dairy and swine industries will lay the groundwork for developing the more process-related emissions models recommended by the NAS.

Developing effective manure treatment technologies for reducing emissions from manure storages

Research Unit:

University of California, Davis
Biological and Agricultural Engineering Department
Animal Science Department
USDA ARS Western Regional Research Laboratory, Foodborn Contaminant Research Unit, Albany, CA

Contact:

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Funding Agencies:

California State Water Resources Control Board (CSWRCB)
USDA Agricultural Research Service (USDA ARS).

Total Funding: $660,000: $600,000 from CSWRCB and $60,000 from USDA ARS.

This research is conducted to address the increasing public concerns over air emissions from dairy operations. The overall goal of this research is to develop effective mitigation technologies for reducing gaseous emissions from manure storages. Several treatment technologies (anaerobic lagoons, solid-liquid separation, anaerobic digestion, and aerobic treatment) are studied for their impact on the production and emission of gaseous pollutants as compared to the manure storage ponds. Research has been carried out to quantify the gaseous emission reductions in manure storages as a result of biological treatment of manure. We have completed laboratory experiments on evaluating the effect of treating manure via anaerobic digestion or aerobic treatment on the gaseous emissions from the storage. We are in the process of setting up experiments to study the effectiveness of surface aeration in lagoons on emission reduction.

The results of our laboratory study are summarized as follows. Screen dairy manure of about 2% volatile solids (VS) was either anaerobic digested or aerobically treated prior to storage in an air-tight vessel. Anaerobic digestion was carried out by using a mesophilic anaerobic sequencing batch reactor of 20-day hydraulic retention time (HRT) and 1 g/L/day VS loading rate and aerobic treatment was done by using an aerobic reactor of 10-day HRT and 2 g/L/day VS loading rate. The treated manure was put into the storage on daily basis for a period of 180-days. All the gases produced during this period were captured and analyzed for VOCs, VFA and methane. The liquid samples were also taken from the storage vessels and analyzed for these compounds. The untreated manure was also stored and analyzed in the

same way as the treated manure and used as the control for comparison. The six-month experimental results showed that both anaerobic digestion and aerobic treatment had significant effects on the reduction of VOCs, VFAs, CH_4, CO_2 and H_2S in manure storages. Anaerobic process performed significantly or moderately better than aerobic process on the reduction of these gases in terms of mass of individual gas per mass of volatile solid fed. Detailed microbiological analyses were also performed to elucidate the effects of process conditions on the microbial community which are responsible for gas production.

Experimental set-up for the laboratory study on the effects of biological treatment on gas emissions from manure storage.

Process-based farm emission model for estimating gas emissions from California dairies

Research Unit:

University of California, Davis
Biological and Agricultural Engineering Department
Animal Science Department
University of California, Berkley
Department of Environmental Science, Management and Policy

Contact:

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Allen Goldstein, ahg@nature.berkeley.edu, 510-643-2451

Dates of Research:

April 1, 2006 to March, 2008

Funding Agencies:

California Air Resources Board.

Total Funding: $299,191

This research addresses the critical need to quantify air emissions from dairies. The aim is to develop a process-based farm emission model that can be used as a scientific tool for estimating and predicting the emission rates of primary air pollutants and developing effective emission mitigation strategies. Specifically, the emissions of volatile organic compounds (VOCs), ammonia, and hydrogen sulfide will be investigated. This project was developed based on our previous research on gas emission modeling and are supported by other projects funded by USDA NRI ($499,000) and Lake Michigan Air Directors Consortium (LADCo) ($250,000) for modeling ammonia emissions from livestock operations.

Feed silage and manure collection and storage facilities are among the major VOC emission sources on dairies, yet very little information is available on their emission rates. This project will focus on these sources. Using both experimental and mathematical approaches, VOC emission rates from each source will be measured and modeled under different conditions. A computer model will be developed for estimating and predicting emission rates under a range of typical conditions. Specifically, these major tasks will be performed over a two-year period:

- Develop and refine gas sampling and measurement techniqu**es** for quantifying the VOCs produced and emitted from dairy feed silage and manure sources.

- Quantify the generation and emission rates of VOCs from silage (fermented animal feed) and manure under different management and environmental conditions.
- Develop mathematical relationships to calculate the generation and emission rates of VOCs from feed silage and manure sources as functions of manure characteristics and environmental conditions.
- Using measurement and other data, develop and populate a process-based computer model that can predict the emission rates of VOCs from different dairy feed silage and manure sources.
- Perform preliminary validation and tuning of the modeling results using available dairy measurement data.

This research will lead to better understanding of VOCs produced in the feed and manure sources on dairies and the processes that control their production and emission; it will facilitate the design of technologies for reducing the emissions; and it will deliver a computer model that can estimate or predict the emission rates of various VOCs under different farm management and environmental conditions. The computer model will be a valuable tool for the air quality regulatory agencies, the scientific community and the dairy industry for assessing dairy emission problems and designing strategies for reducing them.

Effects of dietary crude protein on ammonia emissions from dairy heifers

Research Unit:
University of California, Davis, Animal Science Department

Contact:
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Co-workers: W. A. Jackson, E. J. DePeters, J.G. Fadel.

Dates of Research:
April 1, 2003 to Dec 31, 2006

Funding Agency:
State Water Resources Control Board

Total Funding: $600,000 (present study is part of a large mitigation project)

Dairy operations are considered an important source of atmospheric ammonia (NH^3) emissions impairing air quality. The study objective was to evaluate the effects of dietary crude protein on NH3 volatilization from Holstein heifers housed in totally enclosed corrals. The hypothesis was that nitrogen fed in excess of the heifer's dietary requirements is excreted in urine and feces, resulting in increased gaseous NH3 emissions. Heifer diets were formulated to bracket the NRC nitrogen requirements. Twenty-four, short-bred heifers averaging 495 kg were randomly assigned to four groups of six animals each. Every group was housed in one of four greenhouse-like enclosures (aka "bio-bubbles") that were used to allow for comprehensive measurements of gaseous emissions. At the onset of each treatment period, animal groups were assigned to their rations following a 4x4 Graeco-Latin square design. Diets were formulated to contain 12%, 14%, 16%, and 18% CP, respectively. Diets differed in almond hull, barley, and soybean meal content to achieve the desired CP level. Heifers were fed *ad libitum* once daily for a 16 d period. On d 16, NH3 emissions were measured three times daily (2 hrs. per sampling interval) using an EPA approved sampling train method. Furthermore, random floor grab samples were taken from nine locations on the corral floor of each enclosure to assess pH, surface temperature, and total nitrogen. On d 17, heifers were weighed and blood samples collected to determine blood urea nitrogen. Urine and fecal samples were taken for total nitrogen analysis. Significant differences were found in ammonia emission flux values between the four diets ($P < 0.05$). Dry matter intake increased uniformly across all treatment groups, in response to increased weight gain. The 18% and 12% crude protein diets resulted in the most noticeable differences in urine urea nitrogen, and blood urea nitrogen concentrations. These

results suggest, that feeding diets containing nitrogen levels in excess of the animal's requirement can have a physiological and environmental impact.

Volatile organic compound emissions from dairy cows and fresh waste

Research Unit:
University of California, Davis
Animal Science Department, University of California, Davis
University of California, Berkley
Department of Environmental Science, Management and Policy
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Frank Mitloehner, fmmitloehner@ucdavis.edu, 530-752-3930
Allen Goldstein, ahg@nature.berkeley.edu, 510-643-2451

Dates of Research: April 1, 2005 to June 1, 2006

Funding Agency: Environmental Protection Agency

Total Funding: $70,000

Biogenic VOCs are typically defined as those directly emitted from plants, but approximately 6% of global net primary production is consumed by cattle that carry out enteric fermentation and then emit VOCs that could also be considered biogenic. Current regulatory estimates suggest that dairy cattle in central California emit VOCs at rates comparable to those from passenger vehicles in the region, and thus contribute significantly to the extreme non-attainment of ozone standards. We report proton transfer reaction mass spectrometry (PTR-MS) measurements of VOCs and cavity-enhanced-absorption gas analyzer (Los Gatos Research, Inc.) measurements of methane emitted from dairy cattle in various stages of production, and their fresh waste. Experiments were conducted in chambers at UC Davis that simulate freestall cow housing conditions.

Methane emission factors ranged from 125-374 lb/cow/year. The VOCs with the highest fluxes from cows and waste were: methanol (0-2.3), acetone and propanal (0.2-0.7), dimethylsulfide (DMS; 0-0.4), and p-cresol (0-0.3) in lb/cow/year. Trimethylamine and acetic acid were also abundant. There were additional 10s of other compounds with detectable, but small, emissions from the cows. A few compounds that were likely emitted (i.e., ethanol, formaldehyde, and dimethylamine) were not quantified by neither the GC-MS nor the PTR-MS. The total flux for all measured organic gases (TOG = CH4 + PTR-MS VOCs) averaged 240,45 lb/cow/year for cow and waste and was dominated by methane (98%). TOG flux for waste only averaged 1.1 lb/cow/year, and was instead dominated by VOCs (81%). The PTR-MS VOCs as a percent of TOG (0.9%) emitted from cows and waste under chamber conditions was a factor of 10 smaller than that currently estimated by the California Air Resources Board. In addition, the ozone forming potentials of the most abundant VOCs are only about 10% those of typical combustion or plant-derived

VOCs, implying dairy cattle have a significantly smaller effect on ozone formation than currently assumed by the California Air Resources Board and regional air districts in central California.

Photochemical ozone formation potential of agricultural VOC sources

Research Unit:
Civil & Environmental Engineering, University of California, Davis

Contact:
Peter G. Green, PGGreen@UCDavis.edu, 530-752-8581

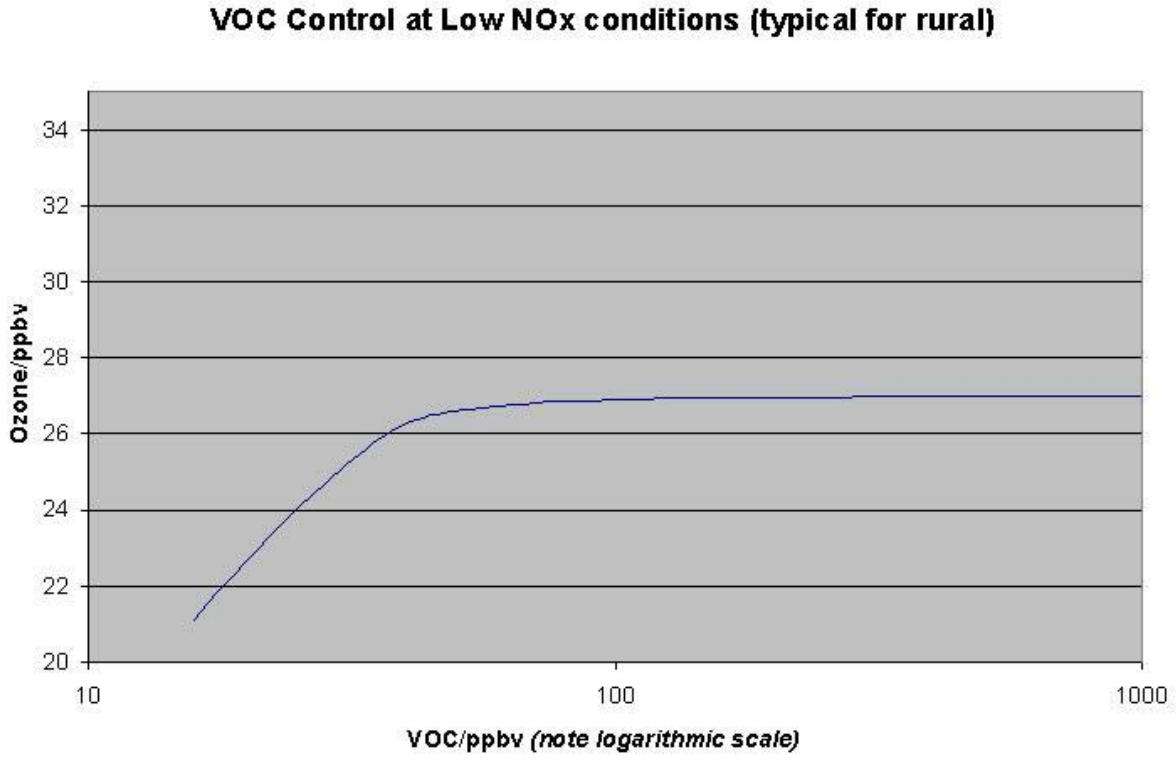
Collaborators:
Bob Flocchini, Terry Cassel, Mike Kleeman, and Rick Higashi

Dates of Research: July 2004 – June 2007

Funding Agencies:
United States Department of Agriculture, NRCS Special Projects

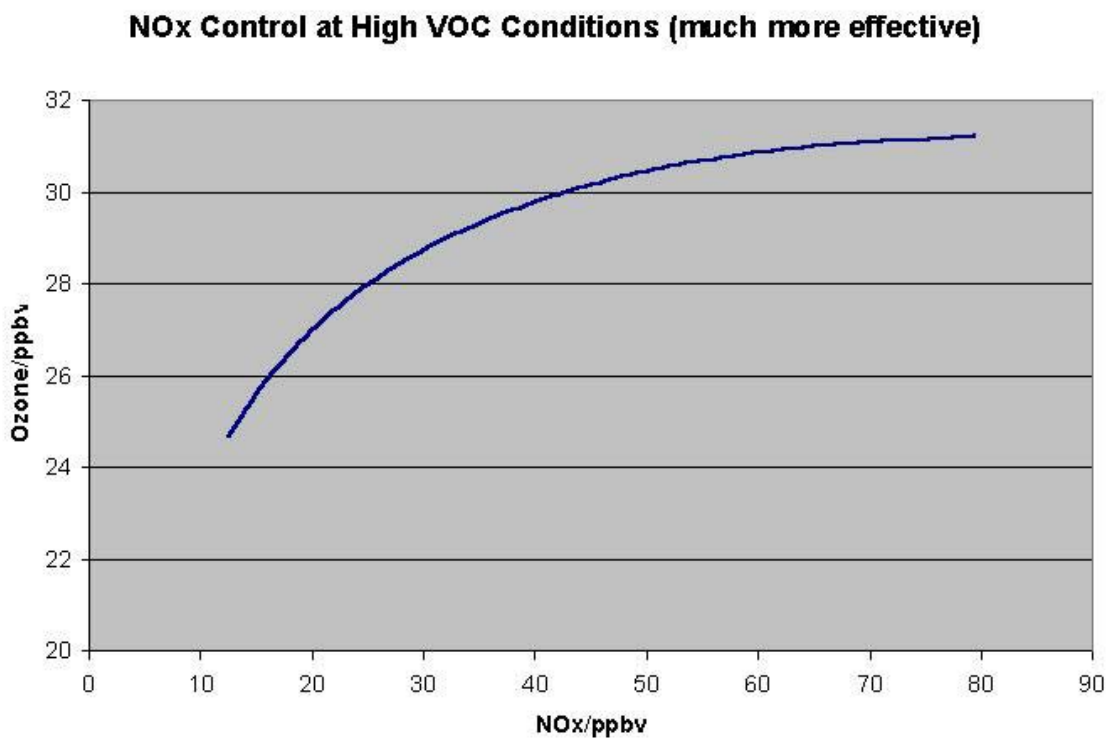
Total Funding: $356,594

This project seeks to improve current understanding of the photochemical ozone formation potential in the unidentified fraction of VOC from agricultural sources. Many local and national initiatives are underway to address air pollution issues involved with livestock manure at confined animal feeding operations (CAFO).



Projects currently underway in the proposing laboratories have identified a mass differential between measured concentrations of total non-methane, non-ethane, organic carbon (tNMNEOC) and total hydrocarbons (HC) upwind and downwind of commercial dairies. It is unknown whether the apparent carbon mass not quantified by traditional HC analyses represents a significant pool of photochemically active ozone precursors.

Select VOC concentrations suitable for ozone formation modeling (e.g. HC) will be measured in air streams impacted by a livestock operation. A tNMNEOC method that can estimate the total mass of the VOC, including the dark-reactive constituents will be applied simultaneously. This will determine how much volatile carbon mass is missed in using the select VOC method. The air stream will be directed into a large (1 m^3) Teflon bag where it will be exposed to a constant light and temperature regime that will be closely monitored. Ozone, NO, and NO_2 concentrations will be measured during the photochemical experiment. From the profile of select VOC established in the first section, a modeling prediction of ozone formation would be made. The difference between the assay results and the prediction would yield an estimate of the photoreactivity of the un-measured VOCs. The TNMNEOC estimate will supply a total mass accounting for the photoreactivity.



Monitoring and modeling of ROG at California dairies

Research Unit:
Center for Irrigation Technology, California State University, Fresno

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Collaborators:
Donald Blake, UC Irvine

Dates of Research: July 1, 2005 to June 30, 2008

Funding Agencies:
California Air Resources Board with matching funding from California State University Agricultural Research Initiative

Total Funding: $693,995

A typical dairy cow in California produces between 80 and 140 pounds of manure each day. Within California's San Joaquin Valley (SJV) there are nearly 1.5 million producing dairy cows. Based on current California Air Resources Board estimates, dairies are a significant source of reactive organic gas (ROG) emissions in the SJV. Quantification of dairy emissions is extremely difficult due to the complexity of the source, with its many dispersed biological process, as well as the challenges in sampling, analyzing, and modeling the collected emissions data. Accurate quantification of ROG emissions is important since it is a component in the reaction that forms ground-level ozone, an air quality category for which the valley is designated as "non-attainment".

Air quality research has been conducted at the CSU Fresno Center for Irrigation Technology since 1998. The initial project was a study of ammonia emissions related to commercial fertilizer applications to various crops in California. The increased interest related to dairy emissions has driven the priority of this research toward the development of methods to sample and model ROG from the wide variety of agricultural operations associated with milk production and the use of dairy effluent for crop production operations. In 2004, two dairies in the SJV were selected for periodic monitoring of ROG and ammonia. The application of the ammonia sampling methodology developed for the previous projects was easily converted to the sampling of ammonia at dairies. The development of collection and analytical methods for ROG has proven to be more difficult. Calculating an emission rate from data collected during the seasonal dairy monitoring required appropriate wind conditions and confidence in the analytical results. Wind conditions were consistently good at one of the dairies and acceptable most of the time at the other. Analytical

problems were such that only results from 1 winter, 1 spring and 3 early summer samples have produced usable emission rates to date.

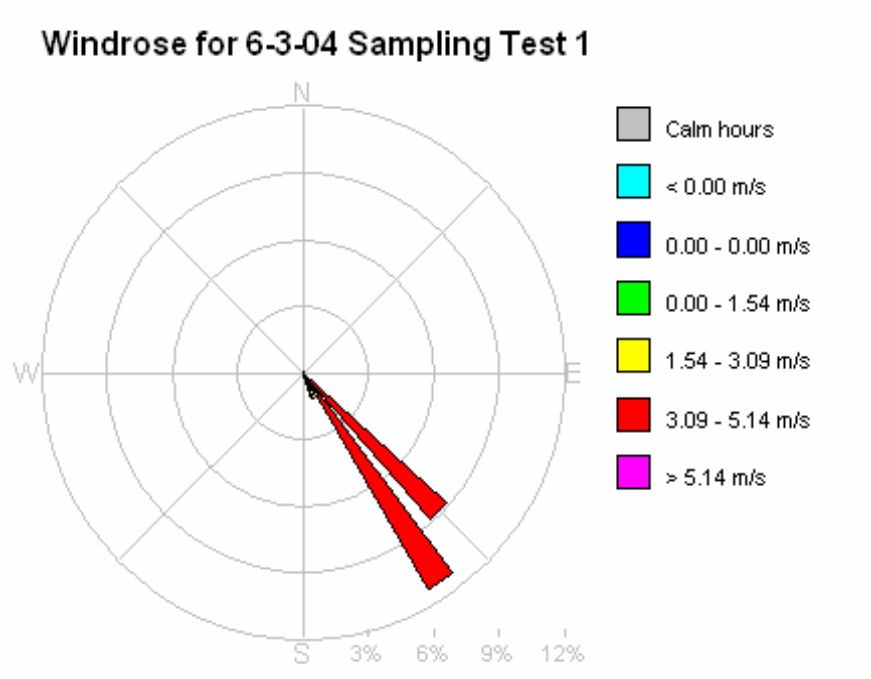
The ROG sampling was done in 6 liter summa canisters according to published methods. Analysis of the first samples, collected in October, 2003 was done at the Oregon Graduate Research Institute by Dr. R. Rasmussen. Subsequent samples were analyzed at CSU Fresno by gas chromatography (Varian Saturn CP3800) with a cryogenic concentration unit and a mass spectrometer (Varian 2100T) according to published methods (EPA-TO-15).

The model selected for this project was the Industrial Source Complex Short Term version 3 (ISC-STv3). It is a steady state Gaussian plume model that can be used to predict downwind concentration from area sources. ISC-STv3 is used to calculate 1-hour average concentrations at receptor locations placed anywhere around the source. The inputs for the model include the relative locations of sources and sampling points, as well as recorded meteorological conditions and emission fluxes. The output from the model is the predicted concentration at the selected receptor locations. The Gaussian model is typically used to determine a concentration at a given location due to a known emission flux. In this case, the concept is used in reverse, to determine an emission flux, from a known concentration. The equation in the model cannot be solved directly for flux so it is necessary to use a multi-step process. This is done using the proportional nature of flux to the predicted concentration. The goal is to determine a flux that will predict the measured net concentration when used in ISC-STv3 with the actual meteorological conditions present during sampling.

An example of the data collected at a 3000 cow dairy located 100 km Northwest of Fresno on June 3, 2004 was modeled to estimate an ROG emission rate of 7.4 lb. ROG/head/year. Emissions from two sampling points downwind of the free stall – flush lane barns were averaged and added to the emissions sampled downwind of the lagoon. The same upwind sampling point was used for each modeled emission rate.

Parameter	Unit	Freestall 1	Freestall 2	Lagoon
Measured TO-15 concentration	g/m^3	101.1	73.5	79.2
Net TO-15 concentration	g/m^3	21.3	14.4	16.2
Emission Rate	lb. ROG/head/year	6.3	3.6	2.4

Emission rates from the two free stall areas were averaged and added to that from the lagoon to calculate the overall emission rate of 7.4 lb. ROG/head/year. Emission rates at this site and one south of Fresno ranged from 1.9 lb. ROG/head/year up to this illustrated example of 7.4.



Four more dairies have been selected for the second phase of the research. The additional dairies each have different methods of collecting, treating and disposing of effluent and solids. The sampling and analytical methods developed in the initial phase of the project will be used and developed further. The primary difference in the second phase will be the collaboration with Dr. Blake of UC Irvine for the development of analytical procedures beyond EPA TO-15. A method for analysis of ROG from animal operations, comparable to TO-15 for combustion gasses, has been found. The primary problem is the need to identify the components of animal emissions of ROG so that suitable GCMS standards can be developed. Dr. Blake is currently analyzing preliminary samples to create standards to be used in both the UCI and CSUF labs.

Quantifying ammonia emissions from California dairies

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Collaborators:
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Dates of Research: July 1, 2005 to June 30, 2007

Funding Agencies:
USDA (Univ. of New Hampshire subcontract)

Total Funding: $187,188

The San Joaquin Valley (SJV), in the interior portion of California, is one of the most productive agricultural regions in the world where most of the state's 5 billion dollar dairy industry is located. Because of the its extent and continuing growth, agiculture is the major source of atmospheric ammonia in California with dairies accounting for roughly 60% of statewide NH_3 emissions. Ammonia is of concern as a precursor to $PM_{2.5}$ and the passage of California State Bill 700 has brought increased scrutiny to NH_3 emissions. The SJV experiences elevated levels of $PM_{2.5}$ usually in winter months. The dominant manure management practice at the dairies is a free stall flush system where water is flushed through barns where animals are housed and fed removing manure and depositing it eventually to a lagoon or storage pond. The effluent is applied several times a year through irrigation systems to surrounding crop land as a means of applying nutrients, water, and disposal of effluent. Dairy producers and agronomist are currently working to develop nutrient

Emission Isolation Flux Chamber Sampling Effluent Application

mangement plans to apply agronomic rates of nutrients while achieving maxium crop yields of forages. Losses of nitrogen occur through the volatilization of NH_3 from the application of dairy effluent. In order to develop accurated nutrient management plans these losses must be quantified.

Because free stall flush manure management systems are not common throughout the national dairy industry little research has been conducted on NH_3 emissions from these systems. Preliminary NH_3 emissions data from dairy manure applications was collected in the winter of 2005/2006 for a project to calibrate a computer simulation model of carbon and nitrogen biogeochemistry for California dairy systems. As part of this project emissions of NH_3 and nitrous oxide (N_2O) will be monitored from California dairy cropping systems focusing on manure applications.

Emissions will be monitored using a USEPA Emission Isolation Flux Chamber. Ammonia samples will be collected with active chemical filter packs consisting of 47mm glass microfibre filters treated with citric acid (3% in 95% Ethanol). The ammonium citrate is extracted from the filter with de-ionized water and analyzed with Nessler's Reagent and a spectrophotometer. Air will be pulled out of the flux chamber with a personal air sampling pumps at a flow rate of 2.0 L min^{-1} to sampling media for 10 to 30 minutes depending on concentrations. Ultra zero air is used to flush chamber at a flow rate of 5.0 L min^{-1} for thirty minutes. Fluxes are calculated with formulas provided in the Measurement of Gaseous Emissions Rates from Land Surfaces Using an Emission Isolation Flux Chamber User's Guide.

Effluent Land Application

The CSU, Fresno research group is currently considering the purchase of a field ready Innova mullti gas analyzer currently used be various researchers across the county. Acquisition of this unit would increase the number of locations characterized from a source as well as quantifying CH_4, N_2O, NH_3 and other gasses. The remaining channels of the analyzer could be used to quantify important VOC's from dairy systems.

Future sampling will be conducted during the Spring and Fall months which are the most common periods to apply dairy effluent in California between cropping rotations of winter forage and summer corn silage. Application of dry manure from scraped corrals or solids separation processes will be monitored in addition to the injection and liquid effluent flood applications.

Monitoring real time emissions of ammonia and methane at dairies

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Dates of Research: July 1, 2003 to June 30, 2007

Funding Agencies:
California State University Agricultural Research Initiative (CSU-ARI)
California Dairy Research Foundation (CDRF)
California Air Resources Board (CARB)
Boreal Laser LTD

Total Funding: $256,970.00 (3 Year)

California is the number one dairy state in the United States, with most operations concentrated in the San Joaquin Valley. While economic returns in this industry are significant, there is the issue of effective manure management, which is associated with problems such as high solids and nutrient contents of the effluent stream, and gas production during the decomposition of manure in storage. Because of health, environmental and economic concerns, there is a need to quantify the gas emissions at dairies. The current objective of this study is to use Tunable Diode Laser (TDL) technology to quantify the spatial and temporal emissions of ammonia (NH_3) and methane (CH_4) from the dairy effluent stream. In the originally proposed project, the objective also included the measurement of hydrogen sulfide (H_2S) gas. However, because of the relatively

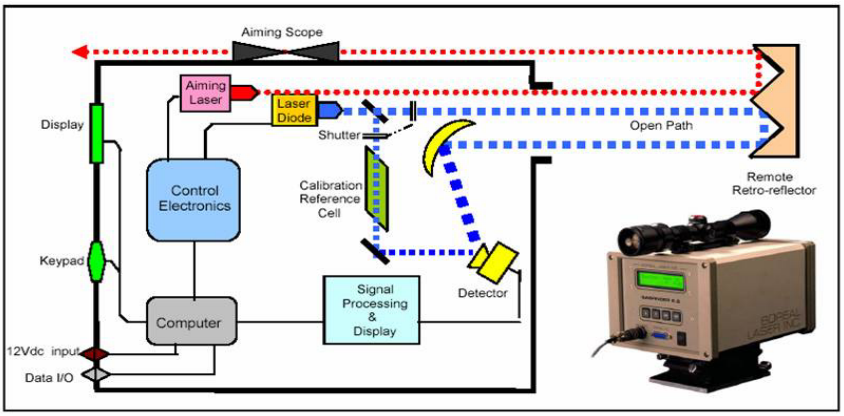

Figure 1. Principle of Operation for a Tunable Diode Laser (TDL)

lower sensitivity of the TDL to detect the levels of (H_2S) on the dairies, we are now focusing on NH_3 and CH_4. A first step in obtaining these emissions is to determine real time concentrations of these gases.

The TDL system measures gas concentration over an open path (Figure 1). It consists of an integrated transmitter/receiver unit and a remote, passive retro-reflector array. The transceiver houses the laser diode source, the drive electronics, the detector module, and microcomputer subsystems. The laser light emitted from the transceiver unit propagates through the atmosphere to the retro-reflector and returns to the source, where it is focused onto a photodiode detector. A portion of the laser beam is passed through an onboard reference cell to provide a continuous calibration update.

In the first phase of the study, we assessed the applicability of TDL technology to determine gas emissions and devoted our efforts to development of methodologies and protocols for sampling the gaseous emissions in real-time. Generally, we found that when the TDL instruments are kept within optimum operating temperature conditions, the TDL technology is suitable for detecting the gas emissions from dairy lagoons during the summer temperatures typical of the San Joaquin Valley, CA. However, during intense fog observed during the Fall and Winter seasons, the lasers fail. More importantly, data collected with the TDL depict the periods of relatively higher emissions occurring during the day and night times which generally go undetected with the other sampling and monitoring techniques used in our other related projects (Figure 2)

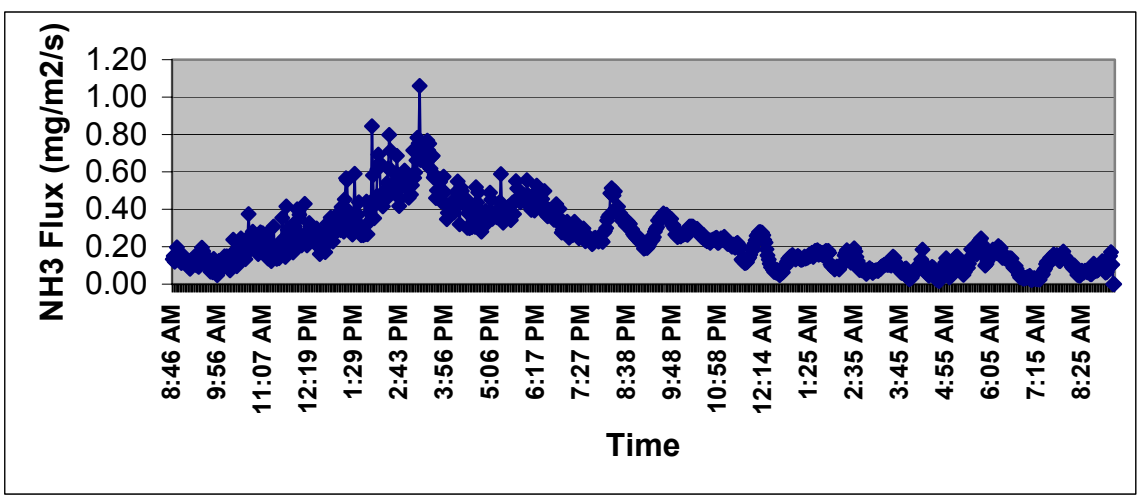

Figure 2. Example of NH_3 fluxes measured with the TDL over a 12-hour period.

For the remainder of the project, the lagoons and free-stall alleys at the various dairies will be monitored for both diurnal and seasonal fluctuations in the emission of CH_4 and NH_3. Real time measurements of gas concentrations will be

correlated with Oxidation Reduction Potential (ORP), pH and dissolved oxygen (DO) of the lagoon water, as well as with prevailing climatic conditions. We will also attempt to use the data collected with the TDL in an EPA approved model to predict downwind concentrations from area sources. The information derived from this research should be useful in making decisions related to management of the dairy effluent stream as the alleys are flushed with the recycled lagoon water, stored in the lagoons and eventually pumped out onto to cropped fields during irrigation.

Developing and applying process-based models for estimating GHG and air emissions from California dairies

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Dates of Research: April 2005 – February 2008

Funding Agencies:
California Energy Commission
USDA NRI program

Total Funding: ~$700,000

It is well known that constant emission factors are not effective for quantifying GHG, ammonia, and VOC emissions from AFOs (NRC 2003). Accurate assessment of air emissions from dairies with emission factors is difficult due to: (1) high variability in the quality and quantity of animal waste, and (2) the numerous factors affecting the biogeochemical transformations of manure during collection, storage and field application. Measurement programs are essential but expensive and thus have not been extensively implemented. Therefore, process-based models that incorporate mass balance constraints are needed to extrapolate air emissions in both space and time (NRC, 2003). There are a number of advantages to developing process-based models of element transformations and emissions from the *combined* components (animal feedlot, manure storage and handling, land application of manure) of AFOs:

- Dynamic, process-based models, developed from laboratory and field studies, **do not rely on constant emission factors**. They assess the impact on emission factors of varying conditions (e.g., climate, storage facility, soils). These models will continue to improve as more field studies are conducted and published, and they do not obviate the need for a strong measurement program.
- By **enforcing a mass balance** in the model (i.e., conservation of mass), the sum of all emission factors are constrained to be ≤ 100% of inputs. This is both good bookkeeping and essential for evaluating trade-offs in mitigation

strategies.

- Full system analysis with dynamic, process-based models can inexpensively and efficiently **evaluate mitigation scenarios** under various conditions, and can help target mitigation toward facility component(s) and/or operation(s) that cause the greatest emissions.
- Simultaneously provide estimates of all emission for **comprehensive assessments** of mitigation efforts. For example, *efforts to reduce methane (e.g. enhance aerobic manure management) may result in increased nitrous oxide emissions that could more than offset gains from methane reductions and result in a net increase in total greenhouse gas emissions*. Therefore, ***well validated models are critical for comprehensive analyses that capture all emissions to air and water***.

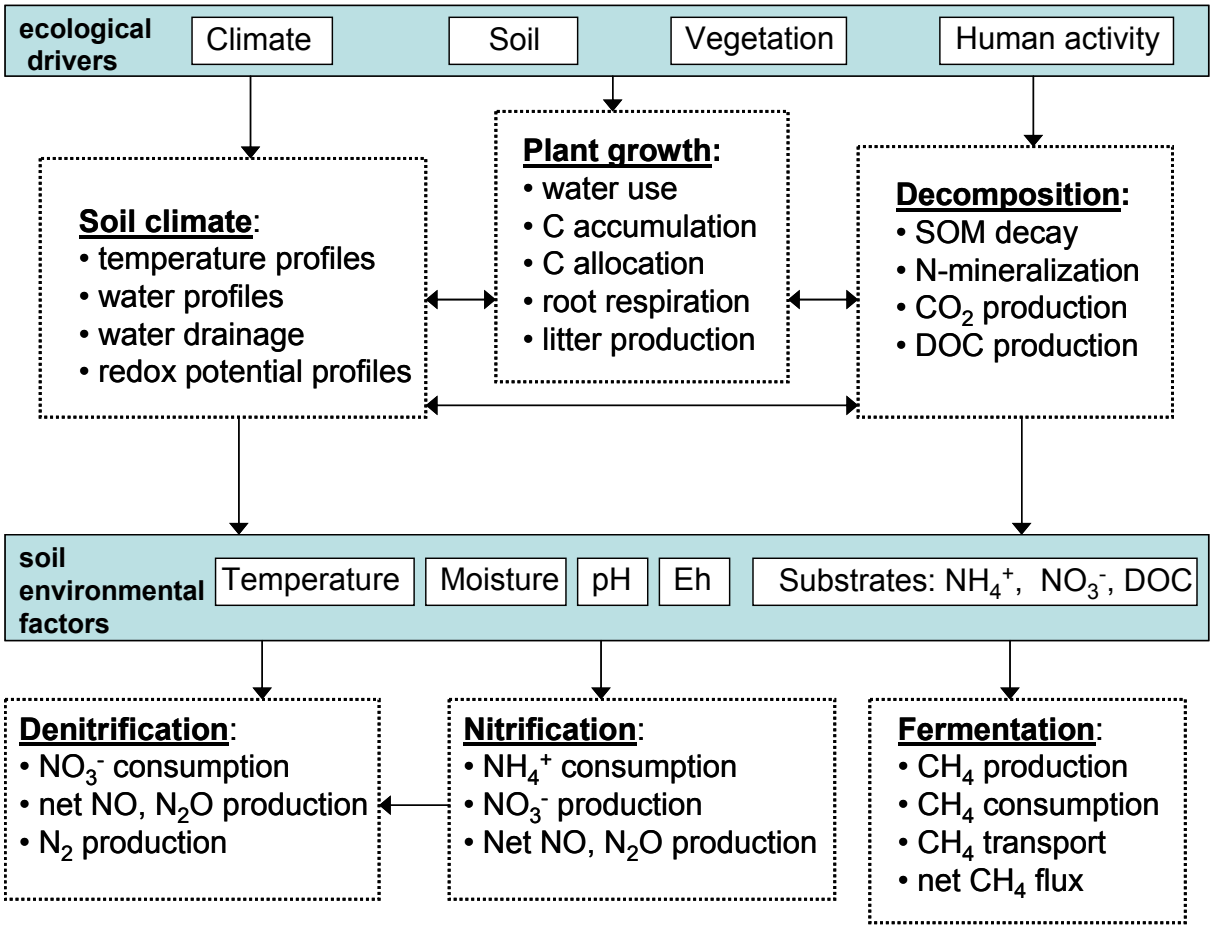

Figure 1. DNDC framework.

A process-oriented computer simulation model, Denitrification-Decomposition (DNDC), was developed based on the biogeochemical concepts for predicting soil biogeochemistry (Image 1). This project is modifying DNDC to create Manure-DNDC, a tool for simulating carbon (C) and Nitrogen (N) biogeochemical cycling in a dairy

operation, tracking the manure life cycle (production, storage/processing, field application) and determining the fate of manure C and N (volatilized, incorporated into soils or vegetation, lost via leaching) for California dairies (Image 2). This task will extend DNDC's applications by integrating the fundamental biogeochemical processes with animal housing and manure management practices. The new model elements will include: (1) integration of detailed biogeochemical processes under animal housing and manure storage conditions; (2) characterization of environmental factors under housing or storage conditions; and (3) characterization of quantity and quality of animal waste at each dairy. The new version of Manure-DNDC will include features to analyze the fate of manure through the incorporation of dairy specific management conditions and local climatological and soil conditions.

In addition to the model development, this project will be collecting field data on ammonia, methane and nitrous oxide emissions for model calibration and validation. Field data will be collected at several operating dairies across San Joaquin Valley and at the UC Davis Air Emission Testing facilities. Emission measurements are being conducted using TDLs, a Photoacoustic INNOVA 1412 analyzer, GCs, and FTIR spectromter.

Table 1. Manure DNDC Components.

	Manure Production	**Manure Storage/Processing**	**Manure Application**
Environmental factors	Air temperature Precipitation Wind speed/direction	Air temperature Precipitation Wind speed/direction	Meteorological data Soil properties Vegetation type
Management factors	Manure quantity and quality Freestall, exercise pens, drylots Temperature Ventilation Duration before removal Removal technique (flushing, scrape)	Temperature Moisture Manure texture Additions Duration before land application	Crop type/rotation Tillage depth Manure application rate Manure C&N content Other fertilization Irrigation Weeding Grazing
Model Simulations	Manure temp., moisture, pH, C&N content Decomposition Denitrification NH_3 volatilization N_2O, NO, N_2, CH_4 emissions N & C leaching	Manure temp., moisture, pH, C&N content Decomposition Denitrification NH_3 volatilization H_2S, N_2O, NO, N_2, CH_4 emissions N & C leaching	Manure temp., moisture, pH, C&N content Decomposition Denitrification N uptake by plants NH_3 volatilization N_2O, NO, N_2, CH_4 emissions N & C leaching

To run the emission models and create an easy to use emission modeling system, spatially explicit data on dairy locations, soils, climate and general agricultural land use are needed. Access to these GIS data layers will enable users to perform statewide, air district, county and even individual dairy emission simulations. We will build a tool to access CIMIS databases (daily min T, max T, precipitation, and solar

radiation) directly into Manure-DNDC GIS database system. We require, at a minimum, hourly temperature, precipitation, relative humidity, wind speed. N deposition data derived from the National Atmospheric Deposition Program (NADP) maps will be built into the system to estimate mean deposition rates at the sub-county scale. DNDC requires input on soil characteristics GIS databases. Soil characteristics will be obtained from the NRCS STATSGO (1:250,000) and SUSRGO (1:12,000 to 1:63,000) databases. Crop and dairy location maps will be obtained from CA DWR land use products. In addition, agricultural census data on livestock counts will be incorporated into the GIS. To enhance the utility of and improve emission estimates from California dairies with process based models, data on dairy practices throughout the state are needed. Statistics to be compiled will include information on dairy structure, manure management practices, trends in diet manipulation impacts on manure characteristics, etc. Sources for these data include surveys and generalized permit data.

Outcome: Biogeochemical process-based tool for quantifying air emissions from California dairies. Tool can be adopted for other regions based on local soils, climate and manure management conditions and practices.

Bacterial population dynamics during waste treatment and subsequent storage in simulated wastewater holding lagoons

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Dates of Research: January 2005 – January 2007

Funding Agencies:
California State Water Resources Control Board
USDA/ARS

Total Funding: $300,000

The dairy industry in California produced over 100 million pounds of waste (manure and urine) in 2005, most of which was spread onto crop fields as a soil fertilizer / conditioner with little or no treatment. This practice is of concern for multiple reasons including: volatile compound emission into the atmosphere, nutrient runoff and leaching into surface and ground waters and the contamination of crop plants by pathogenic bacteria. One way to reduce these risks is to treat the waste before land application. In this study aerobic and anaerobic digestion techniques were used to treat dairy waste before storage in simulated holding lagoons. The microbial population dynamics of the waste stream was monitored using small-subunit ribosomal rRNA gene (16S rDNA) sequence libraries derived from DNA extracted from the waste, the aerobic and anaerobic digester effluent, and the simulated wastewater holding lagoons. The results showed that aerobic digestion altered the bacterial population structure the greatest, with the levels of 8 out of 9 phyla being significantly different. The most notable differences are the >16-fold increase in the phylum *Proteobacteria* and the approximately 8-fold decrease in the phylum *Firmicutes*. Other significant differences included the phyla *Actinobacteria*, *Thermus*, *Planctomycetes*, *Spirochetes*, *TM7*, and *Verrucomicrobia*. Storage of the aerobic digester effluent in a simulated wastewater holding lagoon resulted in increases in the phyla *Firmicutes*, *Planctomycetes*, *Spirochetes*, and a decrease in the phylum *TM7.* Anaerobic digestion resulted in fewer differences, with statistically significant decreases were observed in the phyla *Actinobacteria* and *Bacteriodetes* and significant increases in the phyla *Planctomycetes*, *Spirochetes*, and *TM7*. Subsequent storage of this effluent in a simulated wastewater holding lagoon resulted in a significant increase in the phylum *Thermus*, all other phyla in the library

remained unchanged. Storage of the waste without treatment resulted in the least amount of change with only the phylum *Spirochetes* showing a significant increase. Statistical analysis of the libraries revealed that the waste contained the greatest amount of microbial diversity and that anaerobic treatment resulted in the greatest amount of diversity loss followed by no treatment and aerobic treatment.

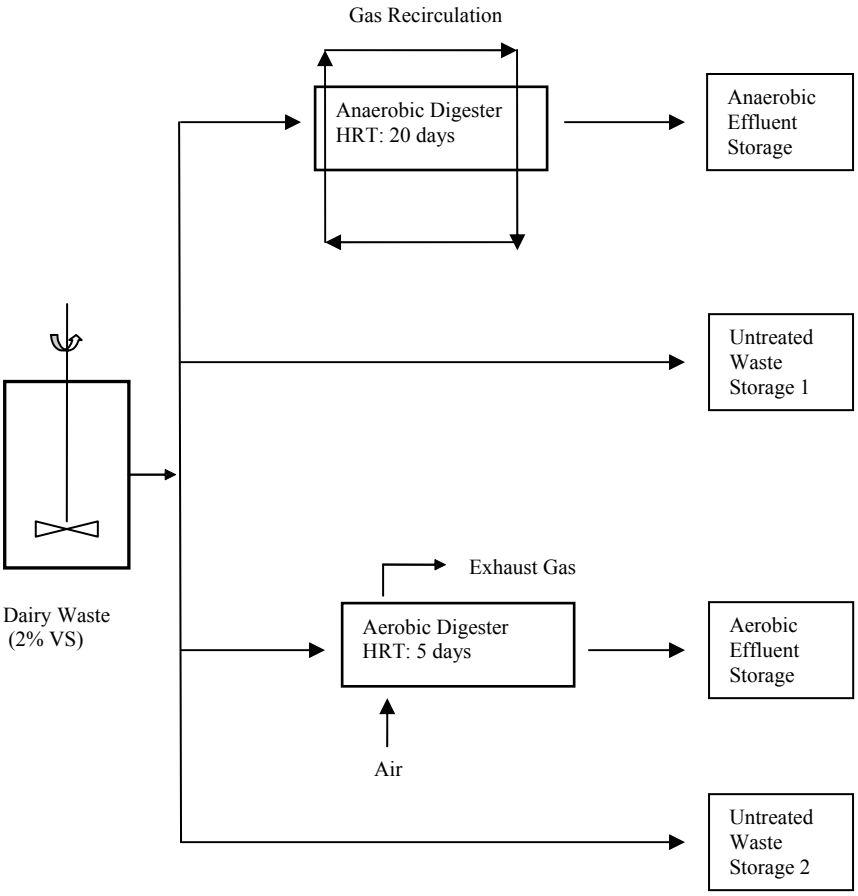
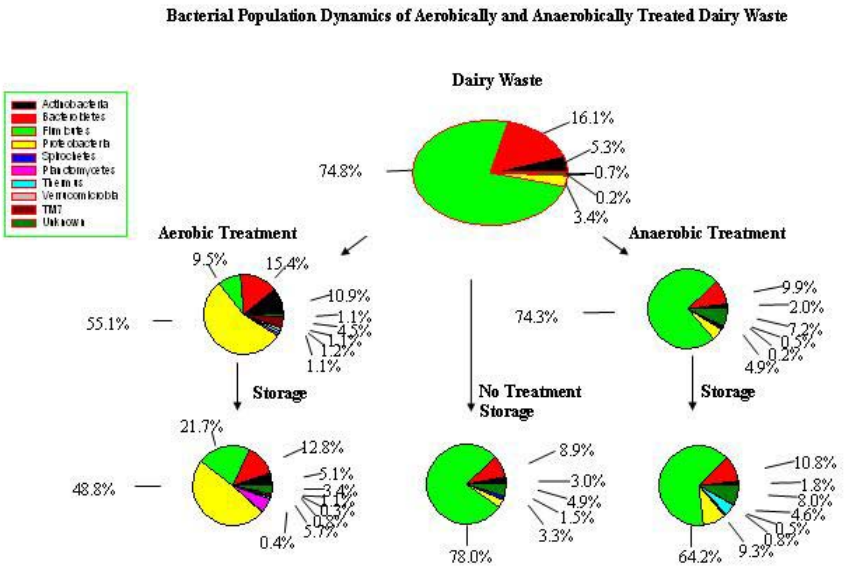


Diagram of Aerobic and Anaerobic Digesters



Bacterial Population Dynamics of Aerobically and Anaerobically Treated Dairy Waste

Air emissions from dairy CAFO's: multi-scale measurements and process based modeling

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Dates of Research: December 2004 - December 2006

Funding Agencies:

USDA - National Research Initiative

Total Funding: $482,279

Confined animal feeding operations (CAFO) are known to be major contributors of atmospheric gaseous and particulate pollutants, but the magnitude and timing of these emissions is poorly known. Various methodologies have been employed to measure CAFO emissions (e.g. flux chambers, lasers, and stationary towers), but these methods are usually limited in their ability to fully characterize the emission plume from a heterogeneous farm, and thus are limited in their ability to quantify total emissions.

Table 1. Summary of gas and particle concentration by sample height.

Measure	HNO_3 ppbv	NH_3 ppbv	NH_4 ppbv (w/w)	CO_2 ppmv	CH_4 ppmv	N_2O ppmv
Total Downwind Average						
Height 1 (Top)[a]	1.11	58.5	0.56	404	2.28	327
Height 2	1.28	126.7	0.63	401	2.23	327
Height 3	1.14	218.5	0.59	405	2.35	327
Height4	1.00	316.4	0.59	406	2.35	328
Height 5 (Bottom)[a]	1.11	382.0	0.62	414	2.47	329

[a] Measurement height varied with each data collection period based on climatic data. The top height is the highest collection height, and the bottom height, the lowest collection height.

This study aims at quantifying emissions of ammonia (NH_3), ammonium (NH_4), nitric acid (HNO_3), methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) from multi-component dairy systems, and examine their spatial, diurnal, and seasonal variability. Using a unique mobile sampling methodology employing large helium blimps and a variety of air and climatic sampling equipment, trace gases and particulates were measured at five heights at three locations downwind, and three heights at one location upwind of two dairies. Heights were chosen based on Gaussian distribution modeling and usually spread from 2 to 40 m.

Volatile gases (NH_3 and HNO_3) and particulates (NH_4 $PM_{2.5}$) were collected using filter packs specially designed for this system attached at each height, with less reactive gases (CH_4, CO_2, and N_2O) pumped to the ground and collected using syringe pumps. In addition, detailed climatic data (wind speed, wind direction, temperature, relative humidity, and pressure) were measured at the five sample heights using a DigiCORA Tethersonde System (Vaisala, Boulder, CO). Average wind speeds, taken at each height along with mean gas and particulate concentrations, can be used to estimate mean horizontal flux at each sample location and be integrated with respect to location to estimate mass flow within the plume. This innovative mass balance measurement technique was designed to overcome the limitations of other sampling systems and provide a spatially resolved characterization of the emission plume. Measurements are currently being made at two dairies, seasonally, over two years from summer 2005 to winter 2006. The dairies have contrasting housing strategies, drylot vs. freestall, but similar manure management systems. Preliminary results show that the concentration of each compound varies spatially with height (Table 1) and location downwind of the farm. Except for HNO_3 peak concentrations of all compounds, were at or near ground level, reflecting a strong local source. Nitric acid peak concentrations were at higher elevations, indicative of its more remote source. Ammonia had the clearest vertical profile, with a max concentration at the lowest sample height (2m), then decreasing steadily with altitude. Most other compounds did not show as clear a pattern, with more variation between heights. Seasonal variation was seen for all compounds, with highest concentrations in the summer for NH_3, CO_2, CH_4, and N_2O, in the fall for HNO_3 and in the winter for NH_4 (Table 2). The increase of HNO_3 and NH_4 in cooler seasons illustrates the preference of the reaction of HNO_3 and NH_3 to form ammonium salts at lower temperatures (NH_4NO_3), as does a higher upwind vs. downwind concentration of HNO_3 and increase in downwind NH_4. Some diurnal variation has been observed, but more data is needed to verify any trends. The goal of the project is to develop and test process based estimations of CAFO air emissions. First, the species, climatic, and spatial data will be integrated into a model that will attempt to show the behavior of the emission plume. Additionally, a model will be created to characterize ammonia emissions by estimating ammonia fluxes from specific farm components and validating those values with data collected by the system. The multi-scale measurements and modeling associated with this project will investigate emissions outputs along with diurnal and seasonal variability. The focus of the project is to provide accurate estimates of problematic trace gas and nitrogen

emissions to the Colorado dairy industry and assist dairy producers in recognizing and mitigating environmental impacts.

Table 2. Summary of gas and particle concentrations by location and season.

Measure	HNO_3 ppbv	NH_3 ppbv	NH_4 ppbv (w/w)	CO_2 ppmv	CH_4 ppmv	N_2O ppmv
Global background [a]	*NA*	*1 - 10*	*NA*	*370*	*1.72*	*320*
Upwind, avg	1.19	0.43	0.51	399	2.01	326
Downwind, avg	1.13	218.7	0.60	406	2.34	328
Seasonal downwind, avg						
Summer	1.00	299.5	0.36	420	2.49	329
Fall	2.93	109.3	0.63	396	2.13	326
Winter	0.35	193	0.81	397	2.29	327
Spring – (May 2006)	--	--	--	--	--	--

[a] Data from Godish, 2004

Effect of the installation of an anaerobic digester on farmstead ammonia, hydrogen sulfide and VOC emissions

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Collaborators:
Idaho Department of Agriculture
Idaho Dairymen's Association
USDA/ARS

Dates of Research: April 2006 – September 2007

Funding Agencies:
Idaho Department of Agriculture
Idaho Dairymen's Association

Total Funding: $325,000

Figure 1. Open-path UV spectrometer.

Micrometeorological techniques will be used to evaluate the effect of the installation of anaerobic digester on air emissions from a dairy in Wendell, Idaho. The project will evaluate the emission of odor and air quality pollutants across the farmstead (farm less the land application fields). The concentrations of ammonia, hydrogen sulfide, and a limited number of volatile organic compounds are made using a collocated open path UV differential optical absorption spectroscopy (UV-DOAS) system, known as the UV Sentry. The UV-DOAS system is installed downwind and perpendicular of a desired sample area and is coupled with 3-dimensional wind velocity measurements at a height of 2m. Three UV Sentry systems (3 UV Sentry systems, 3 sonic anemometers, and 1 weather station) will be installed and operated continuously for 6-months prior to, and possibly during, construction of the digester (April 1, 2006 – October 1, 2006). Once the construction and steady-state operation of the digester is completed, post-construction measurements on farmstead emissions will be conducted during the

same 6-month calendar period (April 1, 2007 – October 1, 2007) as the Pre-construction measurements. Measurements of the following air quality parameters will be calculated: ammonia, atmospheric nitrates, hydrogen sulfide, atmospheric sulfates and volatile organic compounds (VOCs). The gas concentration and wind data are coupled and used to calculate the emission flux through an inverse dispersion analysis using a backward Lagrangian stochastic model (bLS) via the WindTrax model. This methodology has been proven to be effective in measuring the emission rate from area sources where confined sampling using chambers or wind tunnels that may adversely affect the surface conditions over time and do not allow for the evaluation of various control practices while they are being conducted.

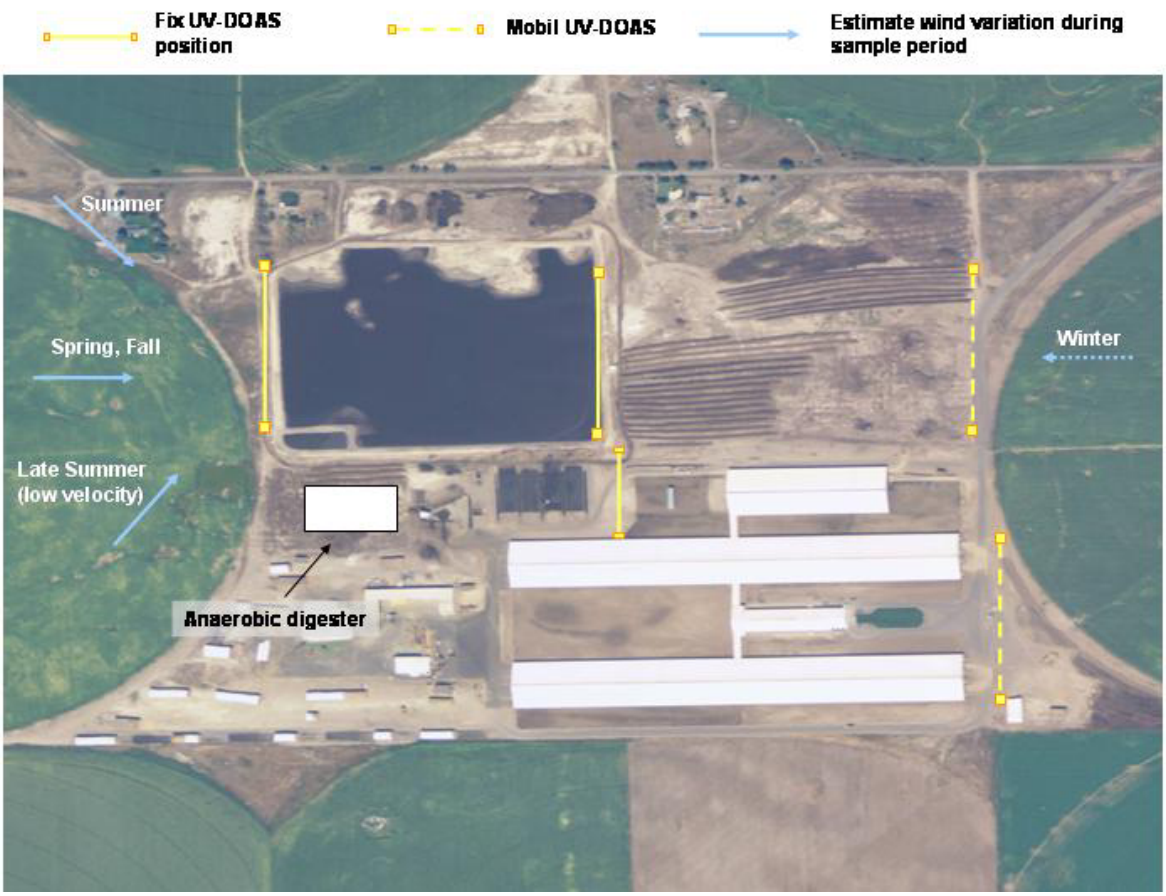

Figure 2. Sampling locations on study farm

Comparison of monitoring techniques to quantify nitrogen and sulfur emissions from dairy wastewater lagoons and open feeding areas.

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USDA/ARS
Idaho Department of Agriculture
Idaho Dairymen's Association

Dates of Research: Summer 2006

Funding Agencies:
Idaho Department of Agriculture
Idaho Dairymen's Association

Total Funding: part of other funded research

This study proposes to evaluate the differences between field-based monitoring methods being used to quantify nitrogen and sulfur emissions from dairies. The study is not intended to develop emission rates from dairy farms, or manure storages, but rather focuses on identifying the differences between monitoring methods and to identify how such assessments would most accurately be done in the future.

Unlike similar studies conducted in North Carolina, emissions will be monitored using all methods at the same time and on the same livestock farm. Specifically, teams using several monitoring methodologies will be given the opportunity to quantify the emissions from a wastewater storage lagoon and dairy openlot over a period of 14-days, respectively. Over the two-week period, each team will be given the opportunity to make their best estimation of emission rates over each hour, day, and entire monitoring period, if applicable.

During the study the following methods may be compared:

- Open-path UV DOAS
- Open-path FTIR
- Wind Tunnel (0.38 m^2) w/ chemiluminescence (nitrogen) and pulsed fluorescence (sulfur)
- δ15N mass balance

- Mass balance using existing NRCS volatilization losses

Lagoon Description:

28-acre (11.33 hectare); wastewater storage lagoon of separated slurry and parlor wastewater from a 6,000-head dairy herd located near Wendell, Idaho.

Openlot Description:

300-ft x 500ft (1.39 hectare: 3.4 acre) openlot pen of 250 lactating cows on a dairy located near Wendell, Idaho.

Data from each of the two-week monitoring events will be prepared by each monitoring team. Data from each then will be compiled, analyzed, and reported.

Odor concentrations downwind of Idaho dairies and heifer facilities

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Idaho Department of Agriculture
Idaho Department of Environmental Quality

Dates of Research: August 2003 – April 2004

Funding Agencies:
University of Idaho
Idaho Department of Agriculture
Idaho Dairymen's Association
Idaho Department of Environmental Quality

Total Funding: $114,000

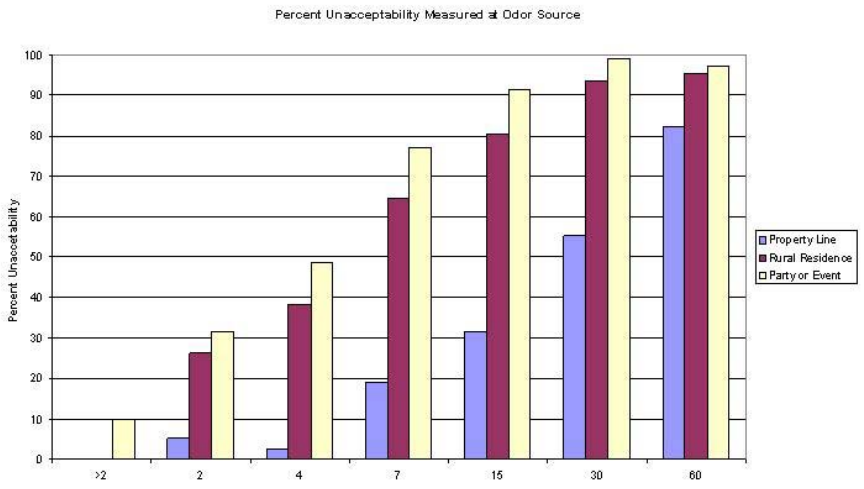
Odor and gas concentrations were sampled on 38 dairies and 15 heifer facilities and calf raising facilities in southern Idaho. Odor was measured using a "Nasal Ranger" field olfactometer and n-butanol to analyze for detection threshold and odor intensity, respectively. Gas concentrations for total reduced sulfur (hydrogen sulfide) were measured at the farm's most probable odor source, 50 m downwind and 200 m downwind, using a "Jerome Meter," and ammonia was measured using Dräger diffusion tubes. Four types of dairies were evaluated:

- Dairy: Openlot corrals with less than 1000 head (9 facilities)
- Dairy: Openlot corrals with more than 1000 head (10 facilities)
- Dairy: Freestall barns with scraped/vacuum manure handling systems: 1200 to 4000 head (9 facilities)
- Dairy: Freestall barns with recycled flush water manure handling systems: 1200 to 4000 head (10 facilities)
- Heifer Facilities: 250 to 5000 head (15 facilities)

The type of manure handling system and management were found to have the greatest effect on odor concentration versus facility size. There were individual facilities within each subject group which emitted odors much less and up to double the group averages. Flush freestall and scrape freestall systems were shown to have the greatest measured odor concentrations, while open-lot facilities had lower

measured levels. Since open-lot facilities occupy 2 to 5 times the area of the equivalent freestall system, it is difficult to make odor emission conclusions from these field measurements. Generally, as the size of facilities increases, odor concentrations also increase. Odor concentrations from open-lot heifer facilities were found to be similar to those of open-lot dairies. Porous geotextile covers for liquid manure storages and wastewater lagoons were found to be effective in reducing odor concentrations by half.

Odors in excess of 15 DT, using a "Nasal Ranger," were found to be objectionable when 50% of panelists responded as if they were located at a rural residence. The same level of odor was found to be objectionable to panelists nearly 80% of the time when the panelists observed the odor during a party or event at a rural residence. The combination of a standard method for evaluating odor acceptability given different land use conditions and dilutions to threshold allow scientists, producers, policymakers, and rural residents to discuss and manage odors on the basis of objective rather than subjective criteria.
Individual gas measurements were not shown to have a high predictive correlation to odor concentration, although TRS/H_2S readings were shown to have higher correlations as distance from the odor source increased. This is likely due to the fact that many of the odorous compounds dissipate rapidly, especially during the daytime, and heavier compounds such as hydrogen sulfide flow and concentrate in low lying areas during still, cool summer nights. Additional research is needed to evaluate the concentration of odors and emission rates of gases from livestock facilities in order to develop predictive tools and models to assist producers, engineers, and regulators in developing livestock facilities that will have minimal odor impact on rural residents.



Relationship between Odor Threshold and Odor Acceptability of Odors Measured at their Source.

Monitoring dairy emissions using open-path FTIR

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Collaborators:
USDA/ARS

Open-path (OP) FT-IR spectra were measured in June, July 2004, and January, March, and June 2005 on fields and a dairy farm in southern Idaho in a cooperative project for monitoring gaseous emissions with the USDA Northwest Irrigation and Soil Research Laboratory (NWISL). Spectra were measured at intervals of 70 seconds over periods of several hours to more than a day. Absorbance spectra were obtained by calculating the ratio of a long-path single-beam spectrum to a short-path background spectrum. In this way, one of the principal drawbacks of OP/FT-IR spectrometry, namely the need to measure a background spectrum that mimics the sample spectrum but without the analyte present was overcome. The concentrations of ammonia, methane and nitrous oxide were calculated by partial least squares regression (PLS). Calibration spectra were obtained by measuring single-beam spectra over a pristine area at several different pathlengths under conditions where the temperature and humidity varied significantly and calculating the ratio of each of these spectra to a short-path background. Randomly scaled reference spectra of each analyte were added to each background spectrum (after adjusting the resolution where necessary) to obtain the calibration spectra.

Two problems were encountered with this approach. The ambient concentrations of methane and nitrous oxide are above the detection limit of our measurements, so the path-integrated concentration had to be adjusted to account for the background level of these analytes. Secondly, the band intensities in the reference spectra of ammonia in two collections were significantly in error. This problem was recognized and overcome after comparing the questionable spectra with high-resolution spectra from NIST and PNNL.

It was found that some of the measured data had to be rejected either when the weather conditions were severe (especially when the wind was high), when the infrared beam was interrupted, *e.g.*, by a bird flying through the beam, or when excessive noise appeared in the spectrum. We have developed a protocol to which each interferogram is subjected. Any interferogram in which the height of the centerburst is outside of certain limits is rejected. A high-pass filter is applied to every interferogram that passes this criterion. A noise level index (NLI) for the wings

of the interferogram is then calculated and any interferogram for which the NLI exceeds a certain level is rejected. With this approach, spectra can be measured and concentrations of the analytes can be calculated automatically with high confidence in the result.

Very recently, we have applied an unusual chemometric technique known as target factor analysis (TFA) to our data. With this technique, the main eigenvectors that contribute to the spectrum can be calculated. In a set of spectra that were measured above a lagoon in a hog farm, an unexpected absorption feature was recognized in the fourth eigenvector. This was recognized as being caused by ethanol that was presumably caused by the anaerobic fermentation of the manure.

In one of these example of the importance of OP/FT-IR measurements, ammonia was shown to be present in the atmosphere above a field that was being treated with dilute manure for several hours after the application. If the field was disked immediately after the manure was applied, the ammonia concentration decayed below 10 ppb almost immediately, presumably indicating that the nitrogen content of the soil was enhanced by this procedure.

Modeling the source of emissions from animal feeding operations

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Dates of Research Reported:
7/1/2004 – 6/30/2008

Funding Agency:
USDA NRICGP

Recently, the National Research Council Committee on Animal Nutrition identified recommendations for addressing emissions from animal feeding operations. A mass balance approach, based on nutrient inputs into Animal Feeding Operations (AFOs), was identified as the best method for estimating gaseous emissions. The advantage of such a model is that estimates of the components can be relayed into a site-specific whole-farm model to estimate emissions for regulatory purposes. Baseline data for emission factors of each of the main farm components (animal housing, manure storage, land application) are vague and perhaps, ill suited for typical AFOs in the U.S. Data from the three largest animal production systems in the USA today, lactating dairy cows, market swine and broiler chickens, are not available even on current feeding and management practices. Thus, obtaining baseline data on the type and amounts of emissions from lactating dairy cows, market swine and broiler chickens is the necessary first step before feed and management changes can be made and documented. We propose to collect baseline data from broiler chickens, growing pigs, and lactating dairy cows for ammonia, hydrogen sulfide, nitrogen oxides, sulfur oxides, nitrous oxide, methane and volatile organic compound emissions. Effective strategies implemented to reduce gaseous emissions, must involve reduction of source emission concentrations in order to avoid merely shifting the location of emission and the form of gas that is emitted. Data will be collected for the animals, as the driving input in a mass balance approach, and used to develop an interactive model for the purpose of site-specificity. Animal diets are the single largest influencing factor on mass of an element excreted, which then has the potential to be emitted in gaseous form. Measures will address the diet variation that occurs nationwide, within the animal industries.

Published abstract resulting from this work:

Powers, W., S. Bastyr, and B. Kerr. 2005. Reduced crude protein effects on aerial emissions from swine. J. Anim. Sci. 83(Suppl 1):527.

The effects of feeding reduced crude protein diets on air emissions was evaluated using groups of barrows housed in rooms with continuously measured gas concentrations and airflows. Pig weights and feed intake were recorded weekly over the course of four feeding phases: G1 (beginning at 24.5 kg BW), G2 (55.3 kg BW), F1 (87.2 kg BW), and F2 (111.4 kg BW). Pigs were offered one of three pelleted isocaloric, isolysinic diets: a control diet (C), a low crude protein diet (LCP) and an ultra low crude protein diet (ULCP), each supplemented with varying amounts of amino acids. Formulated CP of G1 was 22.5, 20.0, and 18.4% for the C, LCP, and ULCP diets. As feeding phases progressed there was a decrease in the formulated CP such that F2 was formulated to contain 16.6, 15.4, and 13.8% CP in the C, LCP and ULCP diet. Dietary treatment had no significant effect on ADG, ADFI or F:G ($P<0.05$). Pigs fed the LCP diet had greater intakes than pigs fed the C or ULCP diets during the grower phases but reduced intake during both finisher phases ($P=0.0287$). A diet effect was observed for average daily ammonia concentrations ($P<0.0001$). Exhaust ammonia (NH_3) concentration where pigs were fed the LCP diet were 16% less than the C diet (3.86 vs. 4.57 ppm). Ammonia concentrations were reduced 25% (2.93 ppm) in the ULCP diets compared to the LCP diet and 36% compared to the C. Airflow-corrected daily average NH_3 emission rates were 26.8, 21.0, and 14.5 mg min^{-1} for the C, LCP, and ULCP diets, respectively, corresponding to a daily mass of NH_3 emitted per kg of animal liveweight, of 88.0, 68.9, and 46.0 mg kg^{-1}. Feeding phase effects were observed for NH_3 concentration, NH_3 emission rate, daily mass emitted and daily mass per unit of liveweight with increases from G1 to G2 followed by a decrease from F1 to F2. Similarly, feeding phase effects were observed for hydrogen sulfide concentration and daily emitted mass of hydrogen sulfide per unit of liveweight. Hydrogen sulfide concentration and emissions were not different between rooms offered the different dietary treatments ($P>0.05$). Diet had no effect on wet or dry mass of manure produced however TKN and NH_3-N concentration decreased with decreasing diet CP (7.9, 6.7, 5.7% and 5.4, 4.4, and 3.5%, respectively for C, LCP and ULCP diets).

Source reduction and mitigation strategies for air emissions from turkeys, laying hens, and growing cattle

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Dates of Research Reported:
5/1/05 – 4/30/09

Funding Agency:
USDA NRICGP

A mass balance model is the most promising approach to estimating gaseous emissions from the vast array of livestock operations in the U.S. and is required to understand the impact of any changes in management (diet, animal, facilities, manure) on the type and quantity of air emissions. Such a model must have clearly defined inputs (ingredients or feeds) and the resulting products (milk, meat) and by-products (feces and urine, gaseous emissions from the animal, gaseous emissions from the manure or excreta). Of primary importance then, are the inputs (diets) because they dictate amounts and types of excretions (solids, liquids and air emissions). However, the magnitude of change in emission mass and form of gas that can be affected by diet remains to be determined directly.

The purpose of this project is to develop baseline emission measures (ammonia, hydrogen sulfide, nitrogen oxides, methane and volatile organic compounds) from growing/finishing cattle (representing 43% of ammonia emissions by EPA estimates), laying hens and turkeys when fed diets typical of industry practice. Following, we will evaluate emissions when treatment diets, that in preliminary studies have demonstrated promise for reducing emissions, are fed. A primary output from this project is development of a matrix of dietary, post-excretion, and mitigation strategies that hold promise for source reduction of emissions from AFOs, with

documented effectiveness for each pre-and post-excretion strategy combination.

Our specific objectives for this grant are to: 1) Identify promising feed strategies by measuring manure/litter emission reductions, in vitro, in ammonia, hydrogen sulfide, methane, and specific volatile organic carbons that occur following implementation of the dietary changes in metabolism studies, 2) Establish emission data for ammonia, hydrogen sulfide, nitrogen oxides, nitrous oxide, sulfur oxides, methane, and specific volatile organic carbons from the animals (growing cattle, turkeys and laying hens) and their manure/litter when fed typical diets (baseline emissions) and reduced emission diets, 3) Evaluate mitigation strategies that involve not only dietary changes but post-excretion manure/litter storage techniques, 4) Apply our findings to the animal and manure handling component of the conceptual farm-level mass balance model proposed by the Committee on Animal Nutrition (NRC, 2003) that estimates emission concentrations and identifies the relative proportion of each form of emission (i.e., N2, NOx, N2O, NH3) based on nutrient flows through a whole farm system, and challenge that model such that the accuracy of the model to predict air emissions is improved, 5) Impart the information learned and strategies identified to students, producers, and policymakers through development of decision-making tools.

The approach to achieving the objectives is to first, evaluate a series of potential diets for laying hens, turkeys and growing cattle, identifying the most promising strategies based on an in vitro emissions assessment procedure. Second, we will establish baseline data, which currently does not exist, of emissions from standard industry diets and compare these emissions to the promising nutritional strategies we have identified. We will identify and account for post-excretion mitigation strategies with litter that, when imposed on distinct model components, have additive or non-additive impacts. The principles and results of the research will be imparted to the end-user implementation at the farm level.

Published abstract resulting from this work:
Wu, W., W. Powers, R. Angel, C.E.Hale III, and T. Applegate. 2006. Effect of diet on air emissions from laying hens of different ages. International Poultry Scientific Forum, Southern Poultry Science Society.

Manure from poultry feeding operations is associated with diminished air quality. The objectives of the current study were to evaluate the effectiveness of feeding a reduced emission diet (R) containing 6.9% of a gypsum-zeolite mixture and slightly reduced CP to 21-, 38-, and 59-wk old Hy-line W36 hens (trials 1, 2, and 3, respectively) on egg production and emissions of NH_3, H_2S, NO, NO_2, SO_2, CO_2, CH4

and non-methane total hydrocarbon as compared to feeding a commercial diet (C). At each age, 640 hens (BW = 1.36, 1.47, and 1.52 kg in trials 1, 2, and 3, respectively) were allocated randomly to eight environmental chambers for a 3-wk period. On an analyzed basis, the C diet contained 18.0, 17.0, and 16.2% CP and 0.25, 0.20, and 0.20% S in trials 1, 2, and 3, respectively. The R diet contained 17.0, 15.5, and 15.6% CP and 0.99, 1.20, and 1.10% S in trials 1, 2, and 3, respectively. Diets were formulated to contain similar Ca and P content. Gaseous concentrations were monitored from each chamber in a sequential manner resulting in 10 to 11 daily observations per chamber. Average daily egg weight (ADEW; 57.4 g), average daily egg production (ADEP; 82.5%), average daily feed intake (ADFI; 92.6 g) and BW change (BWC; 24.3 g), across ages, were unaffected by diet ($P>0.05$). Age affected ADEW (52.1, 58.9, and 61.2 g), ADEP (86.7, 87.1, and 73.7%), ADFI (86.8, 96.2, and 94.6 g) and BWC (65.2, 17.3, and -9.7 g) in trials 1, 2, and 3, respectively ($P<0.01$). Diet ($P<0.01$) and age ($P<0.01$) affected NH_3 emissions. In trials 1, 2, and 3, daily NH_3 emissions from hens fed the R diets (185.5, 312.2, and 333.5 mg bird^{-1}) were less than those of hens fed the C diet (255.0, 560.5, and 616.3 mg bird^{-1}). Daily emissions of H_2S across trials from hens fed the R diet were 4.08 mg bird^{-1} compared to 1.320 mg bird^{-1} from hens fed the C diet ($P<0.01$). Diet ($P<0.05$) and age ($P<0.05$) affected emissions of CO_2 and CH_4. A diet effect ($P<0.01$) on NO emissions and age effect on SO_2 emissions was observed. No diet or age effects ($P>0.05$) were observed for NO_2 and non-methane total hydrocarbons. Results demonstrate that diet and laying age influence air emissions.

Influence of corn co-products on air emissions and nutrient excretions from grow-finish swine

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Dates of Research Reported:
11/1/05 – 10/31/06

Funding Agency:
Funded by National Pork Board

Air emissions continue to draw attention at both the state and federal levels. Practices to reduce the emission of ammonia from animal feeding operations (AFOs) are therefore of great importance to producers as they look down the road to how future regulations might impact their operations. Dietary manipulation provides the best opportunity to prevent emissions from occurring, by reducing or eliminating the precursors necessary for emission formation. Diet manipulation to control nutrient excretions and air emission potential is of growing interest as a first step in cost effective emissions control.

Distillers dried grains plus solubles (DDGS) is a valuable feed ingredient because of its supply of both protein and energy to a ration, allowing it to replace portions of both the corn and the soybean meal in a typical swine diet. The amino acid profile of DDGS, combined with the energy content, may allow nutrient needs of pigs to be met with reduced dietary crude protein. This, in turn, should have positive effects on gaseous and odor emissions. The Midwest continues to expand its ethanol production, generating an increasing amount of distillers dried grains plus solubles (DDGS). Researchers at the University of Minnesota, in particular, have been active in demonstrating the use of DDGS in swine diets and have consistently shown that DDGS can be included in finishing diets, up to 20%, without detrimental performance effects. There is evidence that DDGS can be included at higher levels if pigs are acclimated to DDGS early. However, research that demonstrates the effect of incorporating DDGS into finishing pig diets is scarce with respect to impacts on gaseous emissions. As a byproduct of the ethanol industry, DDGS has the potential

to serve as an economical nutrient source for swine producers who purchase protein and energy sources.

Inclusion of sugar beet pulp into grow-finishing diets at 5%, 10%, and 15% resulted in a reduction of ammonia emission by14% for each 5% increase in sugar beet pulp inclusion (Canh et al., 1998). Diets offered by Cahn et al. (1998) were comprised of alafalfa meal, dried potato protein and soybean oil with Met and Trp added. Inclusion of fructooligosaccharides (FOS) into cat diets resulted in proportionately more nitrogen excretion in the feces and less in the urine (Groeneveld et al., 2000). Incorporation of oligosaccharides into rat diets, also reduced renal nitrogen excretion with greater nitrogen excreted through the feces (Younes et al., 1995). Hindgut fermentation can increase fecal nitrogen while decreasing urinary nitrogen. The impact of this shift is that fecal nitrogen is less easily degraded to ammonia-N and therefore less prone to volatilization. Similar work is needed to assess the impact of different carbohydrate sources in pigs, using diets that represent U.S. feed management. This would include evaluation of novel products of the corn milling industry, beyond just DDGS. A central hypothesis of the proposed work is that dietary inclusion of corn milling products will shift nitrogen excretion from urinary to fecal excretion, thereby reducing direct measures of NH_3 emission even beyond that achievable with reduced crude protein diets alone.

One product of corn milling is dehulled, degermed corn (DDC). By removing the hull, corn is more digestible. Removal of the germ has the added benefit of reduced phosphorus content. Corn germ meal (CGM) contains highly digestible amino acids. While there has been some recent work (Muley et al., 2004, Kendall et al., 2003) evaluating swine performance using these feed ingredients, that work is limited. Furthermore, there has been no work conducted to study the impact of these valuable feedstuffs on gaseous emissions. Increased fiber, hemicellulose, has been shown to encourage an increase the abundance of bacteria able to ferment hemicellulose in the pig hind-gut and should result in an increase in the proportion of microbial nitrogen excretion relative to urinary nitrogen excretion. This increase in microbial nitrogen has been suggested to stabilize stored manure nitrogen such that it is not volatilized into the environment after excretion relative to urinary nitrogen excretion (largely urea). In addition, manure from pigs fed fibrous ingredients often results in manure with lower pH which also reduces the emission of ammonia from manure. The low hemicellulose diet was chosen as recent data in nursery and

finishing pigs reported a dramatic reduction in manure volume. Lastly, the impact of these diet modifications on manure volume, manure composition, and 'odor' components has not been well established.

Research Objective(s):
This research is a cooperative project between scientists at Iowa State University and the Swine Odor and Manure Management Research Unit in Ames, IA. The goal of the research conducted at Iowa State University is to define the impact of three hemicellulose levels through the feeding of different corn dry milling products in diets fed to growing-finishing pigs on air emissions and manure nutrient composition and animal performance. This will be achieved by utilizing corn products from the rapidly expanding dry milling industry: dehulled, degermed corn (DDC), corn germ meal (CGM), and distillers dried grains with solubles (DDGS).

Performance and Excretory Objectives:

1: Evaluate the effects of dietary hemicellulose concentration on growing-finishing pig performance.
2: Evaluate the impact of dietary hemicellulose content on dry matter, nitrogen, sulfur, and carbon excretion; and quantify the generation of malodorous compounds (ammonia, hydrogen sulfide, volatile fatty acids, volatile sulfurs, and volatile phenols).
3: Quantify long-term emissions from manure generated by pigs fed diets varying in hemicellulose content.

Determination of ammonia emissions from ground level area sources (GLAS) of an open-lot dairy

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Dates of Research Reported: June 2004-December 2005.

Funding Agency:
USDA-CSRESS.

Year 2004-2005 Funding: $68,000

A protocol involving surface isolation flux chambers (Figure 1) was used to determine ammonia (NH_3) emissions from the ground level area sources (GLAS) of a 2000- head open-lot dairy during two summer seasons (2004 and 2005) and the winter season of 2005. Flux chambers were shrouded in metal containers (Figure 2) with insulated covers to prevent excessive heating of the chamber by solar radiation and to minimize moisture condensation on its internal surfaces. Ammonia concentration measurements were made using chemiluminescence-based analyzers. The GLAS including open lots (cows on earthen corrals, Figure 2), separated solids, primary and secondary lagoons and milking parlors were sampled to measure NH_3 concentrations. Ammonia emission fluxes were calculated using NH_3 concentrations, cross-sectional area (foot print) of the chamber and the volume of zero air (NH_3 free) circulated into the chamber, and measured using mass flow meters during each 30-minute sampling of a random location within a GLAS. Ammonia emission rates (ER) were then calculated using actual total areas of each GLAS. Additionally, simultaneous temperature and humidity measurements were made for the chamber, GLAS and ambient air using automatic data loggers during NH_3 concentration measurement in summer and winter seasons. Results of the measured NH_3 concentrations and a discussion on the seasonal and GLAS variations of NH_3 emissions will be presented at the 2006 Western Dairy Air Quality Symposium. Also, spatial effects and resulting variations in NH_3 emissions from dry, wet and shaded surfaces within the corral area will be discussed.

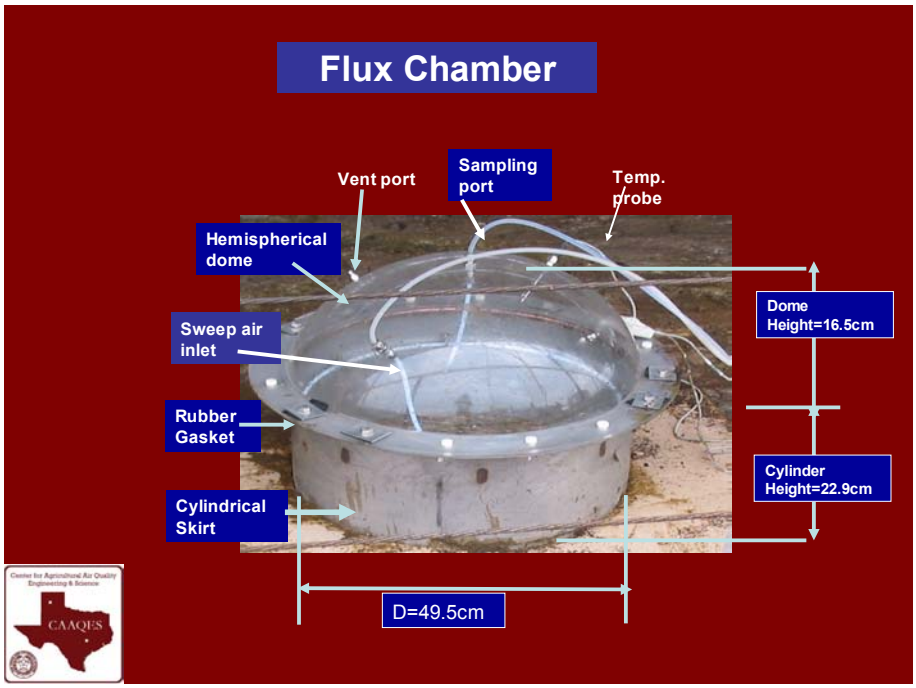

Figure 1. Components and dimensions of a surface isolation flux chamber.

Figure 2. Ammonia emissions sampling with shrouded chambers (background) and analyzers (foreground) in the corral of an open-lot dairy.

Odorous VOC emissions from beef feedlots

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Collaborators:
Dr David Parker - West Texas A&M University

Dates of Research: May 2006 – April 2008

Funding Agencies:
USDA-CSREES Federal Air Quality Initiative

The emissions of odorous VOCs from beef feedlots on the High Plains of Texas will be evaluated using direct sampling. The project will evaluate the emission rates of a number of VOCs that have previously been identified as being significant contributor to the overall odor emissions from beef cattle feedlots. Samples will be collected from either wind tunnels or equilibrium flux chambers from pens and retentions structures at three feedyards in each season of the year. Thermal desorption tubes will be used to capture the target VOCs from the air stream. These samples will then be analyzed using the Varian ATD-GC-MS systems at The Texas Agricultural Experiment Station and/or West Texas A&M University. With the concentrations determined by analysis and the flow rate from the sampling system, the emission rate of each of the VOCs identified can be calculated. The Agilent GC-MS-O system at West Texas A&M University will be used to supplement the determination of target VOC concentration with identification of other significant compounds. Beyond determination of emission rates, this project will be used to elucidate the effect of common management practices on emission of odorous compounds.

Ammonia and hydrogen sulfide emissions from beef feedlot retention structures

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Dates of Research: May 2006 – April 2008

Funding Agencies:
USDA-CSREES Federal Air Quality Initiative

Direct and downwind sampling will be used to evaluate the ammonia and hydrogen sulfide emissions from a beef feedlot retention structures near Hereford, Texas. The project will evaluate direct measurement of ammonia and hydrogen sulfide emissions using a wind tunnel floating on the retention structure surface and indirect measurement of these emissions obtained multi-height measurement in the downwind plume together with back-calculation using a dispersion model. While current understanding does not indicate that the retention structure is a major contributor to ammonia emissions from beef cattle feedyards, it is likely to be the major source of hydrogen sulfide emissions. The concentration of ammonia and hydrogen sulfide will measured with TEI -17C chemiluminescence and TEI-45C pulsed fluorescence monitors respectively, located in two climate controlled instrument trailers. One trailer will be located at the edge of the retention structure where the instrumentation will monitor the concentration of ammonia and hydrogen in the wind tunnel exhaust. The second trailer together with an elevated mast will be located in the primary downwind direction of the retention structure. Sample will be continuously drawn from inlets at different heights on the mast through Teflon tubing to the instruments located in the trailer. Using continuous meteorological observations together with the recorded gas concentration as input, dispersion models will be used to estimate a source emission rate by back-calculation. These results will then be compared with those obtained through direct measurement using the wind tunnel. Through this project, estimates of ammonia and hydrogen sulfide from beef cattle feedyard retention structures will be obtained for each season of the year.

An integrated approach to measuring emissions from confined animal feeding operations at the whole facility scale

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Collaborators:
USDA-ARS, National Soil Tilth Laboratory;
University of Iowa
University of Utah

Dates of Research: April 2005 – September 2007

Funding Agencies:
U.S. Department of Agriculture, Agriculture Research Service (USDA/ARS)
Environmental Protection Agency (EPA)
Utah Department of Agriculture and Food (UDAF)
Utah Division of Air Quality (UDAQ)
Utah State University Research Foundation
Utah State University

Total Funding: ~$1,000,000

Dairy operations produce a variety of particulates and gases that influence air quality. Support operations (tillage and harvest operations, diesel-powered machinery and feeding) are a source of particulate matter that can enter human lungs and cause pulmonary problems. These operations can also be a source of gaseous emissions such as ammonia, odor-causing volatile organic compounds, hydrogen sulfide, greenhouse gases (methane, nitrous oxides) and airborne pathogens. These emissions can negatively impact human health, property values, and the environment. The presence of buildings and other structures often make whole facility measurement capability a requirement for understanding the source strength and characteristics. The ability to use standoff methods to determine the sources, movement and concentrations of emissions on a whole facility basis opens new capabilities for model development and verification.

An integrated system to measure whole facility emission was designed to characterize the complex structures and temporally dependent emission rates often associated with dairy operations. This approach combines state of the art standoff measurement techniques with standard point source monitoring equipment to provide the calibrated, high spatial and temporal frequency data required to develop and

validate the models required for emission reduction and regulation. This effort includes the design, construction and operation of a new multi-wavelength lidar developed to map and track particle emissions. The lidar incorporates a laser emitting simultaneous, pulsed NdYAG laser radiation at 355, 532 and 1064 nm at a pulse frequency of 10 kHz. The system also includes open path FTS measurements for integrated chemical concentrations, and state-of-the-art point measurements of turbulence, particulate and gas concentrations.

This approach was evaluated in a multidisciplinary atmospheric study at a swine production farm in Iowa, and has been applied to a research dairy at USU. Aerosol plumes emitted from the facilities were prominent phenomena, and their variations with temperature, turbulence, stability and feed cycle were studied, using arrays of particle samplers and turbulence detectors. Other lidar measurements focused on air motion as seen by long duration scans of the farm region. These system demonstrations confirm the value of the multidimensional approach for the determination of local and whole facility agricultural emissions from the complex terrain often accompanying these production facilities.

The lidar trailer and support truck set up to survey the USU Caine Dairy Research Facility

View of the Caine Dairy, past one of the remote gas and particulate sensors along the laser path

Dairy-related emissions of ammonia and particulate matter and their influence on air quality in northern Utah's and southern Idaho's Cache Valley

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USU's Caine Dairy Center

Dates of Research: November 2005 – continued

Funding Agencies:
Utah State University Research Foundation (via USDA and USU Space Dynamics Lab);
Utah Water Research Laboratory

Total Funding:
$66,190 (funding inclusive of other project segments)

The Cache Valley, which straddles the northern Utah – southeast Idaho border, often experiences unacceptably high levels of $PM_{2.5}$ pollution, particularly during wintertime inversion episodes. Previous research by Martin et al., has shown the ambient $PM_{2.5}$ is compositionally dominated by ammonium nitrate (NH_4NO_3) and that the Valley is ammonia-rich in regards to wintertime NH_4NO_3 formation. The nitrate component is believed to be attributable to mobile sources (automobiles), and the ammonium component is presumed to come from abundant local agricultural sources. Both Cache County, UT and Franklin County, ID have strong agricultural economies, with agricultural-related receipts of $121.6 million (2004) and $66.0 million (2000), respectively. Dairy operations make up a major portion of this economic sector with 104 dairies registered within the Utah portion of Cache Valley and 74 dairies in operation on the Idaho side. In addition to the dairies and related support operations, other significant agricultural segments in the Valley include a large cattle feedlot and processing facility, two hog farms, and two large egg producers.

As previously indicated, several research studies have been initiated into air quality issues affecting the Cache Valley, including investigations described herein: the quantification and homogeneity of gas-phase ammonia (NH_3) throughout the Cache Valley and investigations into the emission of NH_3 and primary particulate matter

($PM_{2.5}$) from a university-owned research/teaching dairy. An earlier study had shown that wintertime gas-phase NH_3 averaged (monthly) 19 ppb in the Valley's urban center (Logan, UT) and 58 ppb in a rural area (Amalga, UT). To further expand on the understanding of locally-available NH_3, beginning in January of 2006, twenty-five Ogawa passive NH_3 samplers were deployed throughout the Valley and allowed to sample for 4-5 day periods. Upon recovery, the collection pads within the samplers were returned to the Utah Water Research Laboratory (UWRL) and analyzed for collected NH_3. At present, this study is still in progress, but preliminary results suggest several "hotspots" in Valley, gas-phase NH_3 concentrations (see Figure 1). These, and any new, results will be presented, including the areal relationship of the NH_3 concentrations compared to the location of local dairies and other agricultural and non-agricultural related NH_3 sources.

Direct dairy emissions of gaseous NH_3 and primary $PM_{2.5}$ were preliminarily examined in late fall of 2005 by using arrayed sampler deployment, followed by inverse modeling using a commercially-purchased version (Lakes Environmental) of the EPA's Industrial Source Complex – Short Term (ISTST3) model. Although a stand-alone research project, this emissions study, and a similar one at a swine finishing facility in Iowa, were a part of a large examination of the development of a LiDAR system for whole facility analysis direct particulate emissions (Bingham et al.). In brief, the passive Ogawa samplers mentioned above and ten AirMetrics portable MiniVol $PM_{2.5}$ samplers were deployed in and around Utah State University's Caine Dairy and the concentration fields determined via these samplers were to compared concentration fields predicted following to the model. Figures 2 shows a typical concentration field as determined for NH_3 and $PM_{2.5}$, respectively. Additional inputs for the model include on-site meteorology, "best estimated" initial emission rates, and facility structures and layout. As with the above NH_3 study, the model analyses are not yet complete. However, the model input files are nearly complete and it is anticipated that initial results will be available from presentation and discussion. It should also be mentioned that additional support measurements for the LiDAR-based program included multiple optical particle counters and chemical characterization of on-site particulate matter.

Reducing ammonia emissions from dairy waste using enhanced oxygen immobilized-cell biotechnology

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Dates of Research: Jun 2005 – present

Funding Agencies:
Agriculture Research Center, Washington State University

Larger and denser spatial concentration of animal feeding operations (AFOs) has tremendously increased the potential of environmental pollution in the vicinity of these facilities. Besides water quality, air quality is under tremendous threat in these areas. These facilities have, therefore, become subject to strict state and federal regulations in order to protect air quality. *The long term goal of our research program is to develop technologies to mitigate odor, gaseous and particulate emissions from AFOs.* Ammonia is one major gaseous emission from AFOs which may face federal regulations in the near future. The most effective way of reducing ammonia emissions from livestock waste is to reduce ammoniacal-nitrogen or 'ammonia' levels. An environmentally friendly process of removing 'ammonia' from wastewaters is via benign nitrogen gas through biological nitrification-denitrification process. Unfortunately, the process is bogged down by the nitrification process which is relatively slow requiring long hydraulic retention times (HRT) and hence large reactors. A reduction in the cost of the nitrification process can be realized by reducing HRT, reactor volumes, and cost of oxygenating the systems. Immobilized-cell technology has demonstrated potential of accelerating nitrification processes of other types of wastewaters. The use oxygen gas to meet the high oxygen demand during treatment of high organic strength wastewaters has likewise shown potential of cutting the cost of maintaining aerobic conditions. *The overall objective of this research is to develop a cost-effective biological nitrification-denitrification process to enhance adoption of this technology as a control method to mitigate emissions of ammonia from AFOs.* Our approach couples the two aforementioned emerging technologies; immobilized-cell technology and oxygenation using pure oxygen into a treatment system is termed *oxygen enriched immobilized-cell nitrification (OEICN).*

Emissions of ammonia and greenhouse gases from dairy operations

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The contribution of modern agriculture to familiar environmental problems such global warming and air pollution today is significant. With respect to greenhouse gases, about 65% of methane from agricultural sources may be attributed to dairy operations. Most modern dairy facilities use anaerobic lagoons to treat the waste generated; this practice leads to large emissions of methane and nitrous oxide. Closed-anaerobic digestion (AD) of manure has the potential to eliminate those emissions while still conserving more nutrients as well as producing a renewable energy source. On the other hand, the possible transformation of organic nitrogen to ammoniacal nitrogen (AN) and the parallel conservation of ammoniacal nitrogen during anaerobic digestion may worsen ammonia emission during post-storage of anaerobic digestion effluent. In recent years, there has been renewed interest in incorporating the AD technology in dairy operations, not only to reduce greenhouse gas emissions and produce energy but to also mitigate odor problems from these facilities. *The goal of this research is to elucidate the impact of the anaerobic digestion technology in the mitigation of emissions of ammonia and greenhouse gases on a typical dairy operation.* The specific objectives are (i) to obtain baseline emissions of ammonia and greenhouse gases (methane – CH_4, carbon dioxide – CO_2, and nitrous oxide – N_2O) from typical dairy facilities, and (ii) to evaluate the impact of incorporating anaerobic digestion technology on the gaseous emissions from typical dairies.

The chamber-based flux methods are being used to collect air samples for the measurement of greenhouse gases and ammonia fluxes from the respective sources on typical dairies. The concentration of the respective gases in the air samples collected at various sources in a dairy operation are analyzed in a Gas Chromatograph (equipped with TCD, FID, and HID for greenhouse gases) and Chemiluminescence analyzer (for ammonia).

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