Air Quality: Odor, Dust and Gaseous Emissions from Concentrated Animal Feeding Operations in the Southern Great Plains

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A PROGRESS REPORT – YEARS 1 & 2
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A PROGRESS REPORT – Years 1 & 2

INTRODUCTION: Concentrated animal feeding operations (CAFO) in the semi-arid Southern Great Plains face air quality challenges, including odor and dust, ammonia (NH_3), gaseous emissions, particulate matter (PM) emissions, and respiratory health of livestock. The scientific basis for selecting cost-effective abatement options and establishing achievable emission factors for odor, odorous gases (odorants), ammonia (NH_3), hydrogen sulfide (H_2S), volatile organic compounds (VOCs), and particulate matter (PM_{10} and $PM_{2.5}$) has not been developed for the CAFO industry especially open-lot livestock feeding systems. To establish a credible scientific basis for addressing these issues, this research and technology-transfer project involves a federal/state partnership of outstanding engineers and scientists faculty from the following institutions/agencies:

- Texas A&M University System (TAMUS)--Texas Agricultural Experiment Station (TAES); West Texas A&M University (WTAMU); and Texas Cooperative Extension (TCE);
- Kansas State University (KSU); and
- USDA-Agricultural Research Service (USDA-ARS).

This 5-year field and laboratory research project began in June, 2002. It involves more than 20 faculty members from 5 universities or agencies in the Southern Great Plains states of Texas and Kansas, which together account for more than 40% of the nation's supply of fed beef.

OBJECTIVES: The faculty team has addressed the following major objectives:

Objective 1. Emissions Measurement: Characterize air quality emissions from open-feedyard surfaces and holding ponds or lagoons using standardized field and laboratory measurement methods for PM (PM_{10} and $PM_{2.5}$), odor, and selected gaseous emissions (NH_3, H_2S, VOCs). Sub-objectives include:

1.1. Develop/demonstrate accurate, standardized measurement methods.

1.2. Quantify emission rates from corral surfaces, runoff holding ponds, and anaerobic lagoons.

Objective 2. Effective Abatement Measures: Develop and evaluate cost-effective abatement measures for open-lot feeding systems for beef and dairy cattle in the Southern Great Plains. Sub-objectives include:

2.1. Quantify interactions among the air contaminants in Objective 1 in relation to surface-manure characteristics, climatic variables, animal behavior, and management practices.

2.2. Develop and validate selected cost-effective emissions abatement methods.

Objective 3. Scientific Basis for Emission Factors: Develop a scientific basis for applicable air quality protection policies, including appropriate emission factors for PM_{10}, $PM_{2.5}$, odor, and odorous gases for Southern Great Plains feedyards and related ground-level reactive volatile organic compounds (RVOC), **ammonia, hydrogen sulfide, area sources (GLAS).** Sub-objectives include:

3.1. Refine and validate GLAS dispersion models used to predict downwind concentrations.

3.2. Develop accurate emission factors for open-lot CAFOs.

Objective 4. Animal Health & Performance: Determine the impact of feedyard air contaminants on animal health and productivity. Sub-objectives include:

4.1. Determine the effects of dust on ruminant animal health and productivity.

4.2. Explore causal pathways by which feedyard dust might contribute to cattle health disorders.

Objective 5. Technology Transfer: Deliver education and technology transfer programs that address characterization and cost-effective abatement of airborne emissions, scientifically sound regulation of open-lot feedyards and dairies, and effects of emissions on livestock health and performance.

PROGRESS REPORT SUMMARY for Years 1 & 2 (2002-2004)

Objective 1. Emissions Measurement:

Overview--Intensive multi-agency field sampling has been conducted at a 50,000 head commercial beef cattle feedyard (Feedlot C) near Amarillo involving multiple investigators from different agencies on six occasions. Participants represented WTAMU, TAES-Amarillo, BAEN-College Station, and USDA-ARS (Parker, Koziel, Todd, Cole, Parnell, Lacey). A field study involving PM, H_2S and NH_3 monitoring from discrete sources was conducted by BAEN at a combination free-stall and open lot dairy in Central Texas (Parnell, Mukhtar). Data collection and analysis methods appropriate to feedyards and dairies using isolation flux chambers (Koziel, Mukhtar) and micrometeorological/flux gradient approaches (Todd, Cole) were compared, and measurement protocols were refined. Excellent progress was recorded in methods development/refinement and field monitoring research. Techniques for improving concentration measurements for ammonia and PM at dairies and feedyards, respectively, were developed and are being used to refine emission factor estimates. Field measurements of ammonia emissions showed reasonable convergence between two different approaches according to limited field sampling to date. Ranges of values of parameters including feedlot odor, ammonia, hydrogen sulfide and VOCs concentrations and projected emission rates or flux values were identified. Specific investigator progress included the following:

- Odor detection threshold (ODT), H_2S emissions and manure samples were collected weekly from three Texas feedyards along with weather data in Years 1 and 2. The data from the first year of odor sampling went through an exhaustive quality assurance process and a manuscript is near completion (**Parker**). H_2S showed little correlation with odor. A laboratory study (WTAMU) of odor additive testing for reducing feedlot manure was completed. Results of odor monitoring (ODT) upwind vs. downwind of cattle feedyards showed some inconsistencies because of elevated upwind odor concentrations. Pen surface manure was characterized for potential correlations with air quality parameters.
- A study was initiated to evaluate potential odor losses from adsorption to different types of odor sampling bags including commercial tedlar, in-house manufactured tedlar, teflon, foil, and PET (**Koziel & Parker**). Preliminary results indicate that significant losses of VFAs and VOCs occur during the first 24 hrs when measured with SPME; however, very little difference in ODT was observed between immediate, 24 hr, and 48 hr holding times. While the study is ongoing, Tedlar was found unsuited for sampling certain VOC's and VFA's.
- Intensive multi-agency sampling events at Feedyard C were conducted in August 2002; January 2003; April-May 2003; July 2003; January – February 2004; and April 2004. These events involved coordinated monitoring by WTAMU, TAES, BAEN and/or ARS scientists. Monitored parameters included PM, odor, odorous gases, hydrogen sulfide, volatile organic compounds (VOC), and ammonia. Continuous sampling capability for NH_3 and H_2S was acquired and deployed. A surface isolation (flux) chamber (NCSU-design) was used at Feedlot C (**Koziel & Baek**) and a different type of flux chamber (EPA-designed) was used at a central Texas dairy

(**Mukhtar**). The protocol used to determine emission rates in the dairy study was quite different. The results using the Feedlot C and Dairy protocols are being evaluated.

- Ammonia concentrations were monitored both using flux chambers and flux-gradient methods, with continuous and passive samplers at Feedyard C both deployed. Preliminary data on ammonia flux were developed. Diurnal variation of NH_3 was determined and NH_3 flux gradient was tested at the feedlot (**Koziel**).
- **Cole & Todd** collaborated with researchers at USDA-ARS, at Watkinsville, GA to develop complimentary field experiments involving open-path laser and static chamber approaches to ammonia monitoring, in summer 2003 and winter 2004 at Feedyard C.
- A 'mega' flux chamber was constructed with a 32 ft^2 footprint (~50 times greater than the NCSU & EPA flux chambers used previously), and will be used to further evaluate spatial variability in NH_3 emissions within pens **(Parker).** The mega chamber will be supplied clean air from a 500-gallon, trailer-mounted compressed air tank/gasoline-powered compressor.
- Visibility monitoring including passive (colorimetric) and active (transmissometer) were further developed as potential analogs to PM monitoring **(Auvermann).** A simple, systematic, image-processing method was developed to infer changes in visual contrast by comparing RGB histograms of corresponding pixel groups in otherwise identical digital images of the same, standardized color targets. Calibration and testing efforts are ongoing (**Auvermann**).
- Preliminary results indicated ammonia concentrations above a cattle feedyard surface were similar in magnitude using: (a) time-weighted micrometeorological-based measurement using acid-solution absorption, and (b) continuous chemiluminescence monitoring of flux chamber air **(Todd, Cole & Koziel).**
- Air samples collected upwind vs. downwind of an edge-of-feedyard “water curtain” showed promising VOC reductions **(Auvermann & Koziel)**.
- Ammonia concentrations in air decreased with distance downwind of Feedyard C and may have been related to nitrogen excretion rates (**Todd & Cole).** Down wind ammonia concentrations were measured by ARS researchers at Feedyard C from the property line to 800 meters downwind during the July 2003 sampling. Ammonia concentrations at the north property line (10 meters downwind) when the wind was from the southeast, south or southwest ranged from approximately 500 to 1000 micrograms/cubic meter. In general, during the day, concentrations decreased rapidly on the downwind side. During the night, or at other times when air conditions were more stable, concentration decreased at a slower rate. Preliminarily, **(Cole & Todd)** determined decreases in NH_3 concentrations with downwind distance were approximately 15% per 100 m to background concentrations at 800 m from Feedyard C. Preliminary box model estimates of ammonia flux were inconsistent.
- Manure and wastewater sampling and analysis continued to characterize substrates for parameters potentially relevant to ammonia and odor/odorant emissions **(Cole, Todd & Parker).**
- Flux gradient ammonia sampling at Feedyard C was compared to dietary and excreted N, with NH_3 loss preliminarily projected at ~ 47% of excreted N **(Cole & Todd)**. A Bowen-ratio energy balance capability was added, together with physical models of simulated runoff retention ponds.
- Comparative results showed relatively good agreement (+/- 15%) in atmospheric NH_3 concentration between time-weighted micrometeorology-based concentrations using

gas washing **(Todd & Cole)** versus continuously-monitored chemiluminescence for isolation flux-chamber exhaust air **(Koziel & Baek)** during the Winter 2003 intensive sampling field campaign.

- A surface isolation flux chamber was used at random locations within one feedpen at Feedyard C. Preliminary mean summertime NH_3-N and H_2S-S flux values (15-day averages) for summer 2002 were 27.8 μg/m^2/sec and 0.02 μg/m^2/sec, respectively; for winter 2002-03 they were 4.82 and 0.005 μg/m^2/sec; and for spring 2003 they were 30.3 and 0.025 μg/m^2/sec **(Koziel).** Work continues in correlating ammonia and hydrogen sulfide flux with manure pack characteristics.

- Using air samples from a surface isolation flux chamber at different locations within a feedpen, seven volatile fatty acids (VFAs) (acetic, proprionic, isobutyric, butyric, isovaleric, valeric & hexanoic) were estimated as a function of time of day, location, and manure pack characteristics **(Koziel)**. Preliminary concentration data showed VFAs varied 4 orders of magnitude from100 pptv (hexanoic) to 1.5 ppmv (acetic). Preliminary flux varied from 0.2 μg/m^2/sec for acetic acid to 0.005 μg/m^2/sec for hexanoic acid. More than 30 VOCs were identified downwind from a cattle feedyard.

- **Lowry Harper & Ron Sharpe** of USDA-ARS, Watkinsville, GA conducted a cooperating study at Feedyard C from July 5 to August 5, 2003. Ammonia and methane concentrations were measured using open-path lasers and emissions from the feedyard and retention pond were estimated using a Backward Lagrangian Stochastic (BLS) model. Effects of simulated rain and urination on methane and nitrous oxide emissions from pen surfaces were determined using surface flux chambers.

Objective 2. Effective Abatement Measures:

Overview--Weight drop test chambers were used to develop initial simulation of feedlot dust PM_{10} and TSP generation vs. weight/impact (Auvermann/Maghirang, et al.). Abatement treatment evaluations involving chemical amendments (ammonia control) or water application (PM control) proceeded in laboratory scale. Promising results were derived from application of urease inhibitor or humate for ammonia control in laboratory/simulated feedlot conditions; a study was conducted at the WTAMU research feedlot to determine urease performance under field conditions; an apparatus was constructed and a study was initiated to evaluate odor emissions in simulated lagoons; and experimental scale-up to field locations was planned. Water curtain for edge-of-field interception of PM was evaluated further. Certain PI's helped USDA-NRCS develop a state and national sprinkler system standard for PM control that will be used for feedyards under EQIP funding. Laboratory studies of feedlot dust vs. energy inputs and manure properties (depth and moisture content) showed consistent results both at TAES-Amarillo and KSU. Experimental systems for feedlot surface evaporation studies vs. climatic variables were upgraded and preliminary relationships developed. Specifics included:

- Dynamics of the TAES and KSU weight-drop test chambers (WDTC) received engineering attention to improve test accuracy (**Auvermann & Maghirang**). PM emission concentrations were determined to be related to kinetic energy inputs. Intrinsic feedlot dust susceptibility was correlated with surface manure moisture, depth and other test variables.

- Using the Weight-Drop Test Chambers (WDTC), preliminary relationships were established by TAES-Amarillo and KSU between kinetic energy imparted (weight drop) and mass of feedlot dust captured on filters (**Auvermann & Maghirang**). Several parametric experiments were conducted involving manure depth and moisture. The standard source of dust tested at both locations came from a Texas feedyard and had a determined PSD. Considerable progress was made in better understanding the mechanics of cattle hoof actions on PM_{10} generation and effects of water additions on dust suppressions.

- Evaporation rates from simulated feedlot surfaces (weighing lysimeters) containing feedlot manure were established for 9 months at TAES-Etter on 5 of 6 lysimeters. For fall, winter and spring conditions, measured feedlot surface evaporation rates from lysimeters were well-correlated with reference evapotranspiration (ET) values as determined by a microclimate-based, irrigation-scheduling network for the Texas Panhandle (**Auvermann & Marek**). Electronic upgrades were made to the feedlot surface lysimeters measuring evaporation loss as a function of weather variables for dust control/management in that individual load cells were installed on each unit.

- Microlysimeter tests (ARS) were begun to determine ammonia emissions with evaporative drying of simulated feedlot surface manure (**Todd & Cole**).

- *In vitro* evaluation of chemical amendments for odor/gas emissions control continued at WTAMU (**Parker, Cole, Auvermann & Koziel**). Surface treatments of urease inhibitor (NBPT) and humate materials showed positive effects in reducing ammonia emissions. Field experiments for chemical control of odor/odorants were initiated to validate the promising laboratory results.

- A laboratory apparatus was constructed and a study was initiated to evaluate odor reduction with various commercial additives in simulated lagoons (**Parker**).

- An edge-of-field water curtain system at a feedyard near Hereford, Texas was further evaluated, expanding the database 4-fold from Year 1 (**Auvermann**).

- Transmissometers were prepared for installation at an experimental feedlot as a visual means of estimating feedlot dust emissions (**Auvermann**). Preliminary field calibration included work at Feedlot C.

Objective 3. Scientific Basis for Emission Factors:

Overview--Models for converting concentration results from field study protocols to characteristic emission parameters such as flux, emission rate, and emission factors were refined. Emission factor development continued and is being coordinated for all PI's (Parnell). Ammonia losses in isolation flux chambers and tubing were identified experimentally. Gaussian modeling approaches were refined and compared with alternative approaches, with large differences noted between certain modeling approaches. Systematic over-sampling of PM_{10} using FRM approaches was analyzed and addressed with EPA personnel. Specific progress information per PI's included:

- A project focus has been on accurate PM_{10}, $PM_{2.5}$, NH_3, and H_2S concentration measurements with corresponding appropriate calculations of fugitive emission factors for cattle feedyards. Our goal is a sound scientific basis for the emission factors evolving from this study. (**Parnell, Lacey, Shaw, & Mukhtar**)

- **Parnell** serves as lead investigator for calculating PM_{10}, $PM_{2.5}$, NH_3, and H_2S emission factors for all test variables and sites in consultation with the cooperating scientists. Our goal is to insure that the fluxes, emission rates, and emission factors resulting from this study are based upon sound science and that the results are used appropriately in the regulatory process.

- Emission factor data from **Koziel, Mukhtar, Todd, and Cole** for ammonia and hydrogen sulfide are being compared. **Koziel and Mukhtar** are using isolated flux chambers whereas **Cole and Todd** are using measured tower concentrations and back-calculating flux using either BLS, California Box model, or micrometeorological procedures. For summer 2002, **Koziel** reported fluxes of 1,680±1,930 μg/m^2/m NH_3-N which corresponds to 28±32 μg/m^2/s NH_3–N, **or** 34±39 μg/m^2/s NH_3. This would be equivalent to 90±100 lb/1000 head/day for a cattle spacing of 150 ft^2/head. The range would be 0 to 190 lb/1000 head/day.

- **Mukhtar, Lacey,** and **Parnell** are developing a proposed protocol for the isolation flux chamber approach for emission factor determinations. Field data have been collected using this protocol for dairies. **Mukhtar** reported ammonia emission factors of 26±27 for winter conditions and 67±33 lb/1000 head/day for summer conditions for a central Texas hybrid free-stall/open lot dairy.
- **Lacy's** graduate student (**Price**) reported results of back calculated ammonia flux from reported measured concentrations (**Todd and Cole**) using ISCST3 as follows: 6-10 μg/m^2/s NH_3 corresponding to 16 to 27 lb/1000head/day. (This conversion was for a cattle spacing of 150ft^2/head.)
- **Koziel** used a different protocol and flux chamber for his cattle feedyard studies than did **Muktar**. **Mukhtar** used the "EPA" flux chamber and **Koziel** used the "NCSU" chamber. An evaluation of the two protocols is in process. It is hypothesized that the two different protocols and chambers should yield the same flux for the same conditions and location.
- A new low-volume TSP sampler was designed and tested in a constant concentration chamber (**Parnell & Shaw**). Results suggested that this new TSP sampler had less variability and was more reliable for the wide range of concentrations that the high volume samplers typically used to measure TSP.
- Improvements were made in the sampling protocol for PM sampling and the process of back-calculating flux using measured concentrations with the ISCST3 model for feedyards and open-lot dairies. These improvements included the following: All sampling points (receptors) have co-located low-volume PM_{10} and TSP samplers. The ratio of PM_{10} to TSP concentrations provides another estimate of the particle size distributions. These field PSDs can be compared to those obtained using the CCM. ISCST3 was used to back calculate TSP flux using the measured meteorological data, location, and height of the receptor. Particle size distributions (PSD) were performed on all samples using the Coulter Counter Multisizer (CCM). The fractions of PM less than 10 micrometers (μg) from the PSD results were multiplied times their respective TSP concentrations to determine "true" PM_{10} concentrations and fluxes for each receptor. This same process has been relatively successful for other applications such as almond harvesting.
- TEOM real-time monitoring of PM concentrations at Feedyard C was initiated in the summer 2003 sampling trip and repeated in April, 2004 (**Parnel**l). Each TEOM was fitted with a TSP sampling head to minimize errors associated with the FRM PM_{10} sampling pre-collectors. While absolute values of concentrations were not assumed to be accurate, the relative magnitudes of the concentrations were very helpful. The summer sampling trip was unique in that very high concentrations occurred each evening, characterized as step function increases in the period from 9:00 to 1:00 AM. These dramatic increases in concentrations were not observed in the winter/spring sampling periods. **Auvermann** and Sweeten have reported these observations previously and indicated that they were most likely a consequence of cattle activity along with changes in meteorological conditions. We have hypothesized that this step function increase in concentration is primarily a consequence of meteorological conditions. It was difficult to "pin-point" the exact time when the gravimetric measurements of concentration peaked since they are averages over 2-4 hour periods

in the evening. The TEOM data pinpointed the high concentrations as occurring at approximately 11:00 PM for three evenings in a row.

- An improved protocol for dairy farms was developed and deployed for measuring ammonia and hydrogen sulfide emission factors utilizing isolation flux chambers and TEI sensors. Progress was made in determining improved ammonia emission factors for open-lot dairies. Techniques for considering spatial variability of emission sources at dairies were developed (**Mukhtar**). A "process-based" approach for determining the facility emission factor using emission rates from seven different sources and weighting the contributions of each using the respective areas of each source has evolved from our dairy studies.
- A new Gaussian modeling approach with power law component was developed (**Parnell, Shaw & Lacey**). Dispersion modeling results were compared utilizing the following seven methods: Micro-meteorology; Backward Lagrangian Stochastic (BLS); ISCST3 (Gaussian); Box model; Modified Gaussian; AERMOD; and ADMS. This past year's efforts have focused on ISCST3, BLS, and Box models. It should be noted that it is inappropriate to use a non-Gaussian model to determine emission rates or fluxes to be subsequently used in either AERMOD or ISCST3 (both Gaussian models). The Gaussian models are being used for regulatory purposes.
- It has determined that the resulting flux utilizing BLS is approximately 10-times the flux found by back-calculating flux using ISCST3 (Gaussian) (**Lacey & Price**). The impact of this finding is that utilizing the BLS derived flux in the EPA approved ISCST model to predict downwind concentrations would yield concentration values ten-times higher than what would be measured at the receptor. (At the current time, ISCST3 is the EPA-approved model)
- Engineering guidance was provided to USEPA Office of Air Quality personnel regarding errors in PM_{10} and $PM_{2.5}$ measurements using Federal Reference Methods (**Parnell, Lacey, Shaw & Buser)**. The group addressed the inappropriateness of using the over-estimates of PM_{10} and $PM_{2.5}$ concentrations from using FRM samplers for use in regulating agricultural sources. These errors are a consequence of the relatively large size of agricultural PM relative to urban PM and the required performance of pre-collectors associated with PM_{10} and $PM_{2.5}$ FRM samplers. Procedures to account for over-estimation of measured agricultural PM_{10} concentrations were developed.

Objective 4. Animal Health & Performance

Overview--A prototype instrumented test chamber to determine the effects of animal exposure to feedlot PM was completed (Auvermann, Cole et al.). Feedyard dust exposure/isolation chambers for calves were being constructed and equipped/instrumented. Experiments were designed for calf dust exposure and for lung fluid studies. These studies are targeted for Year 3 (2004-2005).

Objective 5. Technology Transfer:

Overview--Technology transfer by PI's included exhibits, radio interviews, conference proceedings papers, news articles, and referred journal articles. Project PI's produced (Jan. 2003 – Aug. 2004) more than 59 manuscripts, published 10 refereed journal articles, and made 45 or more professional presentations. KSU sponsored a Cattle Feeders' Day that featured feedlot dust topics. The PI's also wrote 19 proposals totaling several million dollars. The PI's generated co-funding of $514,000(Year 2) and a total of $1,330,000 in non-federal external funding since the project began. Project coordination meetings with scientists were held in March 2003 (Ft. Worth), September (Amarillo) and December (Dallas). The project's Industry Advisory Council met with the PI's in September 2003 and provided input into project efforts, design and focus. An annual progress report was completed (Years 1 & 2) and the Year 3 work plan was prepared and submitted resulting in Year 3 funding award. A 2-day fee-based training short course entitled "Air Quality Emissions and Equipment Short Course" designed for USDA-NRCS personnel was conducted in January, 2004 in College Station (**Parnell, Shaw & Lacey**). This particular short course was designed for the technical staffs of NRCS and required considerable calculation skills by the participants. A second "management" short course on a similar topic is being developed for NRCS and UC-Davis personnel in California.

Selected Project Publications

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