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Investigators and Project Teams:
Project Director and Principal Investigator (PI):
Dr. John M. Sweeten, Texas A&M AgriLife Research, Amarillo, TX

Objective Co-Coordinators & Co-Principal Investigators (Co-PI's):
Objective A –**Dr. Brent W. Auvermann**, Professor, Texas A&M AgriLife Research and Extension, Amarillo, TX
Dr. Ronaldo G. Maghirang, Kansas State University, Manhattan, KS

Objective B –**Dr. Richard Todd**, Research Soil Scientist, USDA-ARS, Bushland, TX
Dr. Kenneth D. Casey, Texas A&M AgriLife Research-Amarillo, TX

Objective C—**Dr. Calvin B. Parnell**, Regents Professor, Texas A&M AgriLife Research, College Station, TX

Objective D—**Dr. John M. Sweeten**, Texas A&M AgriLife Research, Amarillo, TX
Mr. Daniel L. Devlin, Kansas State University, Manhattan, KS

Co-Principal Investigators (Co-PIs):
Steve H. Amosson, Texas A&M AgriLife Extension Service, Amarillo
Sergio Capareda, Texas A&M AgriLife Research, College Station
N. Andy Cole, USDA-ARS, Bushland, TX
M.S. Borhan, Texas A&M AgriLife Research, College Station
Kay Ledbetter, Texas A&M AgriLife Research & Extension, Amarillo
James C. MacDonald, Texas A&M AgriLife Research, Amarillo
Russell O. McGee, Texas A&M AgriLife Research, College Station
Saqib Mukhtar, Texas A&M AgriLife Extension & Research, College Station
Seong Park, Texas A&M AgriLife Research, Vernon
W.E. Pinchak, Texas A&M AgriLife Research, Vernon
Marty Rhoades, West Texas A&M University, Canyon
Project Administrators:
Ronald D. Lacewell, Associate Vice Chancellor, Federal Relations, Texas A&M AgriLife Research & Extension, College Station.
Raymond E. Knighton, National Program Leader, Air Quality, USDA-NIFA, Washington D.C. 202/401-6417

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USDA-National Institute for Food & Agriculture
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Executive Summary

Objective A. Abatement Measures and Receptor Impacts

- Improved, long-term, seasonally and diurnally resolved databases were developed for ground-level PM_{10} concentrations upwind and downwind of three Texas commercial feedyards, one with sprinkler dust control (Feedyard E) and two without (Feedyards A & C).
- A journal article estimating the percent control of fugitive PM_{10} emissions attributable to use of solid-set sprinkler system in Kansas as compared to conventional manure harvesting was published. PM_{10} control efficiency for a sprinkled Kansas feedyard ranged from 32% to 80% with an overall mean of 53% (based on 24 h PM_{10} values). The effect of the sprinkler system in reducing net PM_{10} concentration lasted for one day or less. The efficacy of sprinkler systems in controlling PM/dust emissions from open-lot feedyards can be improved by higher water application rate and/or longer application duration.
- Percentage reductions in net PM_{10} concentrations due to rainfall events were mostly in the range of 60% to almost 100% for both sprinkled and un-sprinkler-equipped Kansas feedlots, with overall means of 77% for KS1 and 76% for KS2. The effects of rainfall events (with rainfall amounts >10 mm per event) lasted for 3 to 7 days depending on rainfall amount and intensity.
- Effects of pen scraping (manure harvest) showed before vs. after PM_{10} concentration reductions of 40% average (11-61% range).
- A scientifically robust project in 2012 at a commercial feedyard in the Texas Panhandle showed that by decreasing cattle spacing by 50% from the region's average of 150 ft^2/hd to only 75 ft^2/hd the ground-level PM_{10} concentrations ($\mu g/m^3$) were reduced by 54-84%, PM emission flux ($\mu g/m^2$/sec) by 52-82%, and PM emission factor (kg PM/1,000 hd/day) by 76-91%. Two methods that were used to double the cattle stocking density (sq. ft/hd) were (a) cross-fencing with constant feedbunk space vs. (b) doubling cattle numbers in each pen, which halved the bunk space per head. Effects on the cattle performance and health indicators are still being evaluated by the host feedlot company.
- Auvermann and project team executed a four-month field study of stocking density effects on dust emissions and corral-surface conditions during 2012. Out of that work emerged an observation-based survey tool used to categorize the moisture, texture, and bulk density of the cattle feedyard surface. Extensive field surveys were conducted using that instrument during the stocking-density study. It was shown that scoring categories for pen-surface condition were well correlated with both (a) stocking density in the pens and (b) mass concentrations and fluxes of nominal PM_{10} from the pen surfaces. Data from those studies are currently being analyzed and interpreted for publication. Preliminary results were presented at seven county-level feedyard-management meetings in Kingsville, Jourdanton, Perryton, Wheeler, Dalhart, Hereford, and Olton, TX, during the spring of 2013.
- Reverse dispersion modeling with AERMOD was used to estimate PM_{10} emission rates for the sprinkler on-off events in feedlot KS1. Reduction in daily PM_{10} **emission rates** associated with the sprinkler system ranged from 12% to 92%, with an overall mean of 49%. During the evening dust peak period, estimated reduction in PM_{10} emission rates ranged from 21% to 93%, with an overall mean of 61%.

- From measured PM_{10} concentrations and weather conditions, PM_{10} emission rates were determined using reverse modeling with AERMOD. The two feedlots differed significantly in median PM_{10} **emission flux** (1.60 g/m^2-day for KS1 vs. 1.10 g/m^2-day for KS2) but did not differ significantly in PM_{10} **emission factor** (27 kg/1,000 head-day for KS1 and 30 kg/1,000 head-day KS2). These emission factors were smaller than the published U.S. EPA emission factor for cattle feedlots (i.e. 82 kg/day/1,000 head capacity).
- A laboratory evaluation of the dust-control effectiveness of pen surface treatments for cattle feedlots was published (Guo et al., 2011). Topical application of mulches, or water application, significantly reduced PM_{10} emission potential of the simulated pen surface.
- Of the candidate abatement materials tested at KSU, hay and water were the most effective in reducing PM_{10} emission potential. Control efficiencies for hay ranged from 48% with an application rate for hay of 241 g/m^2 to 77% with an application rate of 723 g/m^2. Control efficiencies for water ranged from 42% for an application rate of 3.2 mm of water to 69% for an application rate of 6.4 mm.
- A research project was conducted to assess the efficacy of the urease inhibitor N-(n-butyl) thiophosphoric triamide (NBPT) for reducing ammonia emissions from simulated open-lot beef cattle feedyard surfaces. A refereed journal article was published to summarize this field-scale work (Parker, D.B. et al. 2012). Treatments included combinations of NBPT application rate with or without simulated rainfall. NBPT was applied at rates of zero control, steady (5 kg ha^{-1} every 4 days), or increasing (5 kg ha^{-1} initially, doubled every 4 days up to 40 kg ha^{-1}). For all treatments, mean ammonia emissions from the manure were lower ($p < 0.05$) when simulated rainfall was added (6 mm per 4 days). Mean ammonia emission rates for the NBPT treatments were 26% to 33% of the control, demonstrating that NBPT was effective at reducing ammonia emissions from the manure surfaces in both wet and dry conditions. There were no statistical differences in mean ammonia emission rates for the steady and increasing NBPT applications. Results showed that a steady NBPT application of 5 kg ha^{-1} every 4 days was effective in reducing ammonia emissions from the manure.
- Biological and agricultural engineers conducted a study (Mukhtar et al.) to assess NH_3 mitigation from liquid dairy manure (LM) using tubular acid-filled gas-permeable membranes (GPM) in laboratory experiments; and to evaluate the possibility of scaling up the NH_3 mitigation system for use on AFOs. Laboratory studies showed two GPM systems, one submerged below the LM surface and the other suspended above the LM surface, resulted in nearly 50% removal (diffusion) of NH_3 from the LM in less than 20 days. Ammonia was captured in concentrated sulfuric acid (pH=0.36) as ammonium sulfate solution (by-product). The GPM system was capable of removing NH_3 from the air (headspace) above the LM.
- Effective dust emission control in feedlots aims to improve the feeding environment to reduce the mortality and morbidity rates resulting from the bovine respiratory disease to improve air quality of receptors. An economic study (Park et al.) estimated that a feedlot with capacity over 32,000 head in the Texas Panhandle could save nearly $40,000 per year by adopting dust abatement management practices.
- The applicability of computational fluid dynamics (CFD) in modeling airflow around and through trees as vegetative porous barriers along the downwind edge of feedyards was evaluated at KSU by Maghirang by simulating airflow passing a porous fence (1.2 m high × 0.01 m thick, 50% porosity) using standard and realizable k-ε turbulence models in FLUENT.
- The protocols were then applied to particle collection by a row of trees 2.2 mm tall. Predicted particle collection efficiencies for the trees agreed with available experimental data and ranged from less than 1% for 0.875-μm particles to approximately 32% for 15-μm particles. Results from this study indicated greater effectiveness for reducing larger diameter dust particles, and that numerical simulation with CFD can be used to predict particle collection efficiency of

vegetative barriers. This technique has the potential to advance research on vegetative barriers for dust control for open sources such as cattle feedlots.

- Based on 4.5 years data from AMoN monitoring at Canonceta, the long-term average ammonia concentration has been about 5 ppbv, plus or minus 25%, which is a factor of 500 lower than the recognized odor detection threshold for ammonia, and is a factor of 5,000 below any current worker-health standard. The ambient background NH_3 concentration appears to be increasing by about 2.5 percent per year, which is similar to upwind human population, including in the High Plains region.
- Data from the NADP (TX 43) and CASTNET (PAL 190) sites showed that total (wet plus dry) deposition of reactive inorganic nitrogen (RIN) species at Canonceta is dominated by wet deposition (>60%), but the wet/dry deposition ratio is highly rainfall-dependent. Total deposition of RIN is on the order of 5 kg/ha/yr.

Objective B. Process-Based Emission Models

- Pen surface amendments for mitigating greenhouse gas (GHG) emissions (N_2O, CH_4 and CO_2) from beef cattle feedlots were evaluated under controlled laboratory conditions by KSU. Amendments were: organic residues (i.e. sorghum straw, prairie grass, woodchip); biochar from those organic residues and from beef cattle manure; and activated carbon. Manure samples were collected from randomly selected pens from two beef cattle feedlots in Kansas and used in the experiments, either as dry (0.10 g/g wet basis water content) or moist (0.35 g/g wet basis). For the dry manure conditions, all amendment materials showed significant reduction of N_2O and CO_2 emission fluxes compared to the control (i.e. no amendment). For the moist manure conditions, none of the amendments showed significant effects on GHG emission fluxes during the first 8 days. At 10 and 15 days after application, however, the biochar materials performed significantly better than the control (i.e. no surface amendment) in reducing N_2O and CH_4 emission fluxes.
- The effects of water application (e.g. through rainfall or sprinkler system) on emissions of GHGs (NO_2, CH_4, CO_2) from simulated pen surfaces of open-lot beef cattle feedlots were evaluated under controlled laboratory conditions. GHG emissions from the dry manure were low. When water was applied on the dry manure samples, emission fluxes increased rapidly, just 15 min after water application, and then decreased rapidly. A second but lower peak for all three GHGs was observed 120 h after water application, with peak values that were higher for the moist/compacted manure than that for the moist/loose manure.
- In 2011, 2012 and 2013, four, one week long emission studies (Ken Casey) were conducted each year at two Texas feedyards where 10, 20 cm dia, NFT-NSS flux chambers were used to measure nitrous oxide (N_2O), methane ($CH_{4)}$ and carbon dioxide ($CO_{2)}$ emission fluxes from pens newly vacated (950 flux measurements total). Gas samples from the enclosed chambers were collected into evacuated vials for subsequent analysis by GC. Weekly average CH_4 fluxes ranged overall from 0.1 – 10.54 mg/m^2/hr during these studies. Weekly mean values were 4.57 and 5.78 mg/m^2/hr in 2012 and 2013, respectively under normally dry conditions. Methane flux generally increased diurnally with increasing manure peak temperature.
- The N_2O flux under dry conditions (2011) was 0.3 – 1.2 mg/m^2/hr, whereas in the week in which a 37 mm rainfall event occurred after the first day of sampling, N_2O flux averaged 50.85 mg/m^2/hr. Following a rainfall event, nitrous oxide flux spiked followed by a decline to pre-event fluxes over 3-6 days. The increase in nitrous oxide flux increased in response to a rainfall event was approximately 2 orders of magnitude greater than the diurnal temperature response. In the fall of 2012, under dry conditions, the average weekly N_2O flux varied from 0.12-0.17 mg/m^2/hr. In spring of 2013, under dry, cool conditions at Feedyard C, the weekly average N_2O flux was 0.09 mg/m^2/hr (range: 0.01-0.17 mg/m^2/hr). Nitrous oxide flux generally

increased with increasing manure pack temperature, following a diurnal pattern (similar general trend as for methane).

- Together, these data have contributed to the development and refinement of flux rates for Texas feedyards for three GHG's (N_2O, CH_4 and CO_2). Subsequently, they will lead to development of mechanistic models of N_2O and CH_4 emissions from feedlot pen manure surfaces under normal operating conditions.
- Using the OP-FTIR (open-path/Fourier-transformed infrared) spectroscopy system, upwind and downwind concentrations of N_2O were measured intermittently throughout the year by Faulkner and Casey. Continuous measurement was unsuccessful due to equipment malfunction, but data was available for significant periods of the year. Concentration increases across the yard averaged ~160 ppb N_2O. Data analysis is ongoing.
- MacDonald et al., Texas A&M AgriLife Research, analyzed the positive effects of modern-day cattle feeding technologies on improved cattle conversion efficiencies, which have reduced days-on feed and manure production. These technologies in turn have led to reduced potential for greenhouse gas emissions and reduced carbon footprints for cattle finished at feedlots in the Southern Great Plains. The analysis showed that the additive effects of ionophores, implants, and beta-agonists have resulted in an increased average daily gain of 16 to 26%; decreased total dry matter intake by 2-7%; and reduced feed dry matter- to- gain ratio by 18-36%. On a 150-day feeding period basis, these performance improvements have reduced fecal output by 73-261 lbs per head fed, and have lowered N excretion by 0-8%.
- Cattle consuming steam-flaked corn-based diets produced less methane compared to cattle consuming dry-rolled corn-based diets, according to the MacDonald data. Wet distillers grains (30% inclusion) had no statistical impact on methane production. However, when fed from 0 to 45% inclusion in a calibration study, wet distillers grains linearly increased methane production.
- Neither corn processing method (dry-rolled vs. steam-flaked) nor wet distillers grain inclusion influenced CO_2 production. Feeding 30% wet distillers grains slightly increased the proportion of carbon lost in the urine.
- Respiration calorimetry studies (USDA-ARS-Bushland by Cole, Todd and Waldrip et al.) used 8 steers fed diets based on either steam-flaked corn (SFC) or dry rolled corn (DRC). Cattle diets contained either 0 or 30% wet distillers grains with solubles (WDGS). In the second study, SFC-based diets contained 0, 15, 30 or 45% (dry matter basis) WDGS. Enteric methane losses were 20% greater in cattle fed DRC than in cattle fed SFC.
- When diets contained similar fat concentrations, feeding 15 to 30% WDGS did not affect enteric CH_4 production, but feeding 45% WDGS significantly increased enteric CH_4 production. Increasing dietary WDGS increased dietary protein and urinary N excretion. This could potentially lead to increased ammonia and/or nitrous oxide emissions.
- The estimated carbon –footprint of cattle feeding was decreased by steam flaking because of decreased enteric methane and decreased corn requirement. Despite greater enteric methane emission and probably greater N_2O emissions, the estimated C-footprint of cattle feeding was decreased by feeding WDGS. This was due to a decrease in the quantity of corn required, assuming all the C-footprint of WDGS is assigned to the ethanol production process.
- Background and within cattle feedyard methane concentrations were measured using open path lasers and input into an inverse dispersion model to quantify methane emission (Todd et al. ARS). Other variables included wind and turbulence statistics, animal population, and dry matter intake (DMI). Measurements were completed for 32 days during winter and 44 days during summer, 2010. Methane loss averaged 18.5 g CH_4 kg^{-1} DMI d^{-1} during winter and 9.3 g CH_4 kg^{-1} DMI d^{-1}during summer. Per capita emission rate was 145 g CH_4 $animal^{-1}$ d^{-1} during winter and 79 g CH_4 $animal^{-1}$ d^{-1} during summer. Annualized per capita CH_4 emission rate was 41 kg $animal^{-1}$ yr^{-1}.

- Feeding 20% wet distillers grain in place of corn increased the quantity of dry matter, organic matter nitrogen and phosphorus in manure. Cattle fed diets containing 20% wet distillers grain consumed and excreted more N than cattle fed diets with no distillers grains. Cattle fed diets based on dry rolled corn excreted more N than cattle fed diets based on steam-flaked corn.
- Apparent N volatilization losses (as a % of N intake or N excretion) were greater for manure from cattle fed steam flaked corn-based diets than dry rolled corn-based diets probably due to a higher manure pH. Apparent N volatilization losses (as g/day) were greater for manure from cattle fed diets containing distillers grains but they were similar as a % of N intake or excretion.
- The N:P ratio of manure gave N volatilization losses similar to a total N balance, when manure samples were not contaminated with urine or high moisture content.
- Kinetic and isotherm studies demonstrated that ammonium sorption by feedyard manure was rapid and linearly related to ammonium concentration in solution. Ammonium sorption by feedyard manure was highly influenced by temperature, with 112% more sorption at 4^oC than 22^oC.
- Desorption studies revealed that from 58 to 96% of the ammonium sorbed by manure was readily displaced by exchangeable cations in solution. In addition, up to 81% of sorbed ammonium was rapidly volatilized as ammonia upon exposure to ambient airflow. It was concluded that ammonium sorption may temporarily reduce ammonia volatilization from feedyards, particularly during winter, but is not likely to be a long-term retention mechanism.
- As the dietary ration content of WDG increased from 0-60%, MacDonald et al. (Texas A&M AgriLife Research) found that N intake, fecal output, and urinary output increased linearly. The proportion of total nitrogen excreted (% of N intake) increased from 60% to 70%. The proportion of nitrogen excreted in the urine (% of total N excreted) increased from 60% to 70%. Including a moderate amount (20%) of wet distillers grains in the diet had no effect on the percentage of nitrogen lost due to volatilization. However, with WDGS in the diets more total nitrogen was lost because nitrogen intake increased.
- Grain processing had no effect on route of excretion (urine vs. feces). Feeding dry-rolled rather than steam-flaked corn reduced the total nitrogen lost even though nitrogen intake increased when feeding dry-rolled corn. This resulted in a reduced percentage of nitrogen volatilized from 58.5% to 49.1% of intake. The undigested organic material in dry-rolled corn-based diets, including starch may be effective in capturing excreted nitrogen.
- A modified pycnometer method was developed by ARS researchers (Todd & Cole) to measure particle density of the top loose layer of manure in feedyard pens. Bulk density was determined using manure mass displacement. Specific findings included: Mean bulk density was 0.53±0.02 g cm^{-3}; mean particle density was 1.74±0.02 g cm^{-3}; and manure porosity was 0.69. The pen surface moisture content exceeding 60% water-filled pore space, considered the threshold for denitrifying conditions necessary for the production of nitrous oxide occurred on 14 to 21% of days. These data will be used as state variables in process-based modeling efforts.
- Hales et al. (2012) studied the effects of increasing concentrations of wet distillers grains with solubles in steam-flaked corn-based diets on energy metabolism, carbon-nitrogen balance, and methane emissions of cattle. As a result of greater N intake, total N excretion increased linearly ($P < 0.01$) with increasing WDGS inclusion in the diet. Fecal C loss and CH_4-C respired increased linearly ($P < 0.01$) when WDGS concentration increased in the diet, whereas, CO_2-C respired decreased linearly ($P = 0.05$) as WDGS concentration increased. They concluded that CH_4 production as a proportion of GE increased linearly ($P < 0.01$) when WDGS concentration in the diet increased. Total N excretion, fecal C loss and CH_4-C respired increased linearly with increasing concentration of WDGS in the diet.
- Samples of rations, feed ingredients, fresh feces, pen surface manure, and manure stockpiles were obtained at monthly intervals over a one year period from 2 feedyards in Texas and two in Kansas (Todd & Cole). Samples were analyzed for dry matter, organic matter, nitrogen, and

phosphorus. Estimated N volatilization losses, based on a total N balance, were similar to NH3-N losses measured using open path lasers and the bLS model. Fecal N losses were not significantly affected by dietary crude protein content, however, once animal protein requirements were met, urinary N excretion increased rapidly with increasing N intake.

- Ammonia emissions were measured on a near-continuous basis at two commercial cattle feedyards. A two-year database of ammonia emissions and other relevant variables was constructed (Todd and Cole). Combined with previous work at Feedyard C, this research represents one of the most comprehensive databases of ammonia emissions available. Findings included the following:
  - Manure N content and N: P ratio were greater in winter than summer. N-content of air-dried manure was not affected by dietary N content.
  - Mean monthly ammonia emissions were strongly correlated with mean monthly temperature, and the relationship can be used to predict ammonia emissions from Southern High Plains feedyards.
  - Emissions during summer were about twice those during winter, while spring and autumn emissions were intermediate. Annualized ammonia emissions at Feedyard C ranged from 90 to 170 g NH_3/animal/day, and averaged 96 g NH_3/animal/day over all the studies.
  - Two year annual (and average emissions) for Feedyards A, E, and C were 119 and 76 g/hd/day in summer and winter, respectively, and were 98 g/hd/day overall.
  - We recommend an annual emission factor of 40 kg NH_3 per animal per year for beef cattle feedyards based on one-time capacity.
  - Greatest emissions were observed when crude protein in cattle rations exceeded the nutrient requirements of beef cattle of 10-13%, depending on stage of feeding cycle.
  - Ammonia loss as a fraction of nitrogen fed to cattle averaged 41% during winter and 69% during summer. On an annual basis, 54% of fed nitrogen was lost as ammonia. Cattle feeders that meet recommended crude protein in rations can expect to lose half of fed N as ammonia.
- Manure from the WTAMU Experimental feedlot was strip-applied at a rate of 20 Mg ha^{-1} during two field trials. Open path lasers were used to measure ammonia concentration upwind and downwind of the manure strips. Downwind ammonia concentration increased from background level of 20 ppb to almost 300 ppb immediately after application, but they decreased to background level within 72 hours after manure application.
- Two process-based models, the recently developed Manure-DNDC (DeNitrification-DeComposition) model and a refined version of the Integrated Farm Systems Model (IFSM) that incorporates a beef module, were evaluated for predicting ammonia emissions from open-lot beef feedyards in the Southern High Plains. To improve the predictive capacity of Manure-DNDC, IFSM, and other existing process models, a meta-analysis was conducted using data from 12 individual feeding trials, representing 47 dietary treatments and 255 animals. Empirical models were developed that predict daily urinary and fecal nitrogen excretion by beef cattle. Findings included the following:
  - Both the IFSM and Manure-DNDC models were sensitive to key parameters that influenced ammonia production and volatilization. Model predictions correctly tracked seasonal variations in ammonia emissions. Model output reflected differences in emissions due to dietary protein concentrations fed to cattle.
  - Simulations run with Manure-DNDC and IFSM revealed that predictions of daily feedyard ammonia emissions were within 71% to 81% agreement ($p < 0.001$) with two years of measured ammonia emissions from two of the experimentally monitored commercial feedyards in Deaf Smith County, Texas.
  - Annual per capita emission estimates made with Manure-DNDC and IFSM were within 3% to 24% from observed per feedlot animal capita emission rates. In contrast, a current

emission factor in use by the USEPA for beef cattle has underestimated annual emissions by as much as 79%, demonstrating that process-based models can provide improved ammonia emissions estimates for inventory and policy purposes.

  - Statistical analysis identified that daily nitrogen excretion by beef cattle in urine and feces could be predicted based solely on daily nitrogen intake or concentration of crude protein in the animal diet.

- Simple, but robust, empirical models were found to be useful to predict nitrogen excretion in urine and feces with up to 95% accuracy. Existing process-based models for ammonia emissions could be further improved by incorporating empirical equations that more accurately estimate the proportion of total nitrogen that is excreted in the form of urine.
- Researchers at Texas A&M AgriLife and Kansas State developed data that can be used to describe physical processes that control PM emissions from beef cattle feedyards. Expected relationships between the intrinsic dust susceptibility, S, and manure depth and moisture content were realized in benchtop simulations (Razote et al., 2006). Critical moisture levels (w.b.) of 20-25% for dust control and 25-30% for optimal compaction were verified.
- Near visible infrared (NVIR) spectroscopy techniques were developed under a companion USDOE grant to examine and reliably predict ash content of solid feedlot manure/biomass (FB) or dairy biomass (DB) mixed with varying soil content. A basic tool for rapid on-site testing of FB or DB quality as a biofuel could be developed as the NVIR research progresses (Preece, S.L. 2008). More recent experiments by the air quality project team (2011) have shown the reliability of this method also in evaluating surface manure moisture content. This capability can potentially benefit in-field determination of moisture status compared with critical moisture regimes needed for feedlot PM abatement.
- Odors near AFOs are generally caused by odorous VOCs emitted from manure as the mixture of feces and urine. USDA-ARS/Bushland and WTAMU researchers determined specific VOC emissions from frozen feces and urine of cattle that had been fed steam-flaked corn (SFC)-based diets containing 0, 15, 30, or 45% WDGS. No differences in flux were detected across dietary treatments for phenol, indole, skatole, or 4-methylphenol ($P > 0.23$).
- There were no significant differences in odor activity value (OAV) across treatments for feces, and only a tendency for dimethyl disulfide in the feces ($P = 0.09$). Thus, there was no obvious indication that feeding WDGS in conjunction with SFC affects flux of odor or odorous VOC from beef manure. The summed OAV was three times higher in the urine than feces. A single odorous compound (4-methylphenol) accounted for 97.6% and 67.3% of the OAV in urine and feces, respectively. Therefore, engineering or dietary strategies to reduce odor from beef cattle manure should focus on controlling or reducing 4-methylphenol concentrations in the urine and feces.
- A variety of flux chambers and wind tunnels were used to measure emission fluxes of ammonia and VOC's at beef feedlots and dairy farms, without regard for inaccuracies caused by varying air flow rates or conditions. Parker et al. developed a water evaporative flux ratio correction factor (EFRCF) to improve the accuracy of field-measured VOC and NH_3 chamber flux measurements. In a field study, the USEPA flux chamber and a small wind tunnel (SAFR = 1 L min-1) with sweep air flow rates (SAFR) of 5 L min-1 and 1 L min-1, respectively, both underestimated the true field emissions of VOC, with EFRCFs of 2.42 and 3.84, respectively. EFRCFs are recommended for all but the driest of soil and manure conditions.

Objective C. Dispersion Modeling, Regulation and Emission Factors

- Parnell and colleagues used co-located FRM (federal reference method) PM_{10} samplers versus TEOM monitors, the former corrected for particle size distribution (MMD or mass median particle diameter). Wind direction acceptance criteria was ± 45° of prevailing S to N wind direction. Feedyard C monitoring data from Auvermann was selected for the study. The sampling results and analyses lead to correction factors that depended on concentration and particle size. They determined that:

a) For low PM_{10} concentration (<100 μg/m^3) and low MMD (< 10 μm): FRM results = TEOM results;
b) For high PM_{10} concentration (> 100 μg/m^3) and high MMD (> 10 μm): FRM results = 0.6 TEOM results;
c) Where oversampling biases were noted, FRM results = 0.5 TEOM results.

These correction factors did not yet include the effects of the evening dust peaks (EDP) at 1800 – 2200 hrs. on average daily concentrations. From TEOM data, average daily concentrations for 20 hrs/day non-EDP conditions were as follows: September – 169; October – 107; November – 43; and December – 63 μg/m^3.

- Inputs to AERMET pre-model and AERMOD models were addressed, along with a comparison of measured and modeled results. After applying data-smoothing techniques, the derived emission factors for PM_{10} for feedyards for 20 hours/day excluding the evening dust peaks averaged 11.5 lbs PM_{10}/day/1,000 head (range from 3-36) for the period of September through December annually.
- Among more than 200 odor-causing volatile organic compounds (VOCs), phenol and p-cresol are two prominent odor-causing VOCs found downwind from concentrated animal feeding operations (CAFOs) (Borhan et al., 2012). The VOC emissions from cattle and dairy production are difficult to quantify accurately because of their low concentrations, spatial variability, and limitations of available instruments. To quantify VOCs, a protocol following U.S. Environmental Protection Agency (EPA) Method TO-14A was established based on an isolation flux chamber method and a portable gas chromatograph (GC) approach. The general objective of this research was to quantify phenol and p-cresol emission rates (ERs) from different ground-level area sources (GLAS) in a free-stall dairy during summer and winter seasons. Two week-long sampling campaigns using a free-stall operation in central Texas collected samples during winter (29) and summer (37) from six specifically delineated GLAS (barn, loafing pen, lagoon, settling basin, silage pile, and walkway). Thirteen VOCs were identified, and the GC was calibrated for phenol and p-cresol as the primary odorous VOCs. The overall calculated emission rates (ERs) for phenol and p-cresol were 2,656 ± 728 and 763 ± 212 mg hd^{-1} day^{-1}, respectively, during winter. Overall phenol and p-cresol ERs were calculated to be 1,183 ± 361 and 551 ± 214 mg hd^{-1} day^{-1}, respectively, during summer. In general, phenol and p-cresol ERs during winter were about 2.3 and 1.4 times, respectively, higher than those during summer.
- Capareda and colleagues used flux chambers and a portable GC at commercial dairy and feedlot operations to measure RVOC and GHG emission rates and to estimate EF's. They found highly variable sources at the dairy facilities and less variability at the feedyard. They found that 78% and 17% of the methane (CH_4) emission rate (ER) from the dairy facility was from the primary and secondary lagoons used for manure/wastewater treatment, although these lagoons occupied only 8% and 15% of the total surface area. However, 81% of the nitrous oxide (N_2O) emission rate came from open lots that represented 45% of the surface area, while the loafing pens (13% of area) contributed 12% of the N_2O emissions. Aggregated estimated summer ER's for CH_4, CO_2, and N_2O were 834; 7,085; and 5.4 g/hd/day, respectively.
- By contrast, the feedyard methane emission rates came mainly from the feed pen surfaces (51%), runoff retention pond (48%) or compost piles/windrows (1%), each representing 89%, 5%, and 6% of the emitting surface areas, respectively. N_2O emissions came from the pen surfaces (81%), retention ponds (2%), and compost piles/windrows (17%). Aggregate estimated ER's for CH_4, CO_2 and N_2O were 3.8; 1,192; and 0.52 g/hd/day, respectively.

- Dairy emission rates were 219, 6 and 10 times higher than those from the feedyard for CH_4, CO_2 and N_2O, respectively. In terms of CO_2 equivalents, aggregate ER's from dairy and feedyard facilities tested were 24.77 and 1.43 kg/hd/day, respectively.
- Current "best estimate" emission factors were presented in short courses for air quality regulators. Short courses (3) were presented to the Texas Commission on Environmental Quality (TCEQ). Four short courses were presented for CenSARA (Central States Air Resource Agencies) in Texas and Kansas in 2011. In 2012, one short course was developed and presented for CenSARA in Iowa. These short courses were developed with air pollution regulatory personnel as target audiences and addressed PM characteristics, measurement techniques, dispersion modeling, abatement equipment and methods, permitting and many other technical issues. Technical training using dispersion modeling and TAMU-derived emission factors were developed to supply participating engineers with correct interpretations of Federal air quality USEPA rules.
- Dispersion modeling results using TAMU-derived emission factors were provided to USEPA and to members of the USDA-AAQTF (Agricultural Air Quality Task Force).
- Technical issues with regard to the ability of cattle and dairy operations to be in compliance with a new NAAQS for $PM_{10-2.5}$ as a property line concentration (not-to-be-exceeded) were studied and recommendations were developed for regulatory personnel and the cattle industry. CAAQES has a record of more than 5,000 PM samples, including particle size distribution, bulk density, particle density, and ash content. A researchable data base library was constructed to make this data available to consultant, researchers and regulatory personnel.
- Recommendations for an objective sound science method for determining the mass fraction of crustal PM_{10} emitted by cattle and dairy operations were developed. Continuous PM monitoring data at feedyards were utilized with other data to develop procedures that can differentiate between crustal PM from feed alleys, cattle alleys, materials handling, adjacent fields, etc. vs. crustal PM from feed pens.
- A second OP-FTIR system was installed by Casey and Faulkner on the southern, predominantly upwind side of feedyard C in December 2010. This OP-FTIR system has had a record of very high data completeness (>95%) with only minor periods of time lost to routine service activities and prolonged power outages. Data from the upwind and downwind OP-FTIRs were analyzed. Preliminary data analysis indicated concentration rises of ~ 160 ppb N_2O across the feedyard. Back-calculated emission rates using WindTrax for CH_4 and N_2O were 45.68 and 14.56 $\mu g/m^2/s$ on average during warm dry months.
- Static and dynamic flux chamber emission rates had similar systematic uncertainties in emission factor determination for both CH_4 and N_2O measurements according to analysis by Faulkner and Casey. Source-specific methods such as flux chambers require more labor compared to source integrated methods (such as OP-FTIR) due to the large number of samples needed to overcome to the spatial heterogeneity of large area sources. After averaging the emission factors calculated from each sample to account for spatial heterogeneity, the total systematic uncertainty for source specific methods increased to 70.6% and 18.5% for CH_4 and N_2O measurement, respectively. Source-integrated sampling techniques had an average systematic uncertainty of 15.2% when measuring CH_4 and N_2O due to the dominance of the air dispersion modeling required by each method to determine an emission rate.
- OP-TDLAS (Open-path Tunable Laser Absorption Spectroscopy) was limited by the reduced number of compounds it is capable of detecting (including N_2O), but it is the least costly of the source integrated methods and measures CH_4 more precisely than OP-FTIR methods. OP-FTIR systems are capable of measuring concentrations in real time, much like the OP-TDLAS, but are capable of measuring a vast array of compounds without the requirement of reference gases.

- Source-specific methods are capable of individually characterizing the multiple sources of GHGs present in a large area source, while source-integrated methods account for the temporal and spatially heterogeneous aspect of large area sources. When source-specific and source-integrated methods are utilized simultaneously, Faulkner and Casey found it is possible to more accurately determine emission factors than if either were used on their own.

Objective D. Technology Transfer to Stakeholders

- Investigator meetings were held as follows: February, 2011 (Irving, TX) and January, 2012 (Amarillo, TX). The outputs from these meetings are summarized in **Appendix A**.
- Auvermann and Texas Cattle Feeders Association staff presented seven (7) county-level feedyard-management meetings in Kingsville, Jourdanton, Perryton, Wheeler, Dalhart, Hereford and Olton, Texas and conducted a series of producer's workshops in May 2013. The workshops featured the latest research updates concerning PM emissions from cattle feedyards, along with data from a parallel study on land application of cattle feedlot manure and its soil nutrient water and air quality effects. Presentations also included an evaluation of stocking-density manipulation for control of fugitive PM_{10} from cattle feedyards by Auvermann.
- Jim MacDonald and Brent Auvermann presented papers on "Green Technology Commonly used in Cattle Feeding" that is reducing carbon footprint in cattle feedlots, along with "The Carbon Cycle and Beef Production" at the Southern Beef Symposium in Amarillo, January 18, 2011.
- Annual research updates to the Research Committee of the Texas Cattle Feeders Association included Auvermann's presentations of "Air/water Quality Research and Manure Demonstration-Project Updates," and "The Anatomy of the Evening Dust Peak at Cattle Feedyards and Dairies".
- The first module of the Faulkner/Auvermann policy-relevant summary document, pertaining to ammonia (NH_3), was delivered to TCFA for review and comment. The 8-page "Ammonia" summary document covered regulatory content of ammonia and related nitrogen species; feedyard sources of ammonia; emissions measurement; methods; emission rates; mitigation options; and highlights for the feedlot manager. It is a good model for the other planned modules, which are in various stages of preparation.
- Faculty/scientists involved in this project made at least 22 presentations to the scientific community, industry producers and consultants; they presented 24 papers, abstracts or scientific posters at professional meetings; and published 32 peer-reviewed journal articles and book chapters. Two (2) M.S. Theses were produced. A draft compendium of fact sheets, papers and other materials was compiled as a "Cattle Feedlot Air Quality Handbook" (B.W. Auvermann, editor).
- In-depth short courses (8) were prepared and presented to state regulatory, air quality officials at venues in Texas (TCEQ & CenSARA), Kansas (CenSARA) and Iowa (CenSARA).
- A website was maintained and improved, with links to project-specific news articles, publications, and eXtension and webinars/websites.
- By working with the Livestock & Poultry Environmental Learning Center at the University of Nebraska, project investigators published and disseminated materials via eXtension. Project specific material included (5) peer-reviewed eXtension bulletins, one video program, and eight (8) webinars,e.g. "Dust Control from Animal Activity on Open Lots", with USDA-NRS. These materials were made available through the air quality section of the Animal Manure Management eXtension website (Stowell and Heemstra).
- Five (5) additional fact sheets on air quality emissions and abatement practices were published through the on-line website of Texas A&M AgriLife Extension Service.
- The scientists received co-funding that totaled $893,429, including both internal and external competitive grants. This represents nearly a 1:1 ratio of project funds ($1,014,428) from USDA-NIFA received vs. leveraged funds.