Air Quality: Odor, Dust & Gaseous Emissions from CAFOs in the Southern Great Plains—

A Project Overview

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Saqib Muhktar, BAEN, TAMU, College Station

April 13, 2005
Research Project Funding

- **Grantor**: USDA-CSREES
- **Funding (net):**
  - Year 1-- $ 612,500 --completed
  - Year 2—$ 812,631 --completed
  - Year 3-- $ 835,770 --underway
  - Year 4-- $ 994,511 —proposed work plan.
  - Year 5--?
Participants

- **Research Partners**
  - 23 investigators, 5 univ./agencies
  - Texas A&M University System
    - Texas Agricultural Experiment Station—Amarillo & College Station
  - West Texas A&M University
  - Texas Cooperative Extension
  - Kansas State University
  - USDA-ARS—Bushland TX

- **Cooperators:**
  - Texas Cattle Feeders Association
  - Kansas Livestock Association
Objectives & Coordinators

1. **Emissions characterization** —
   David Parker, WTAMU, Canyon TX

2. **Effective abatement measures** —
   Brent Auvermann, TCE/TAES, Amarillo

3. **Accurate emission factors** —
   Calvin Parnell, BAEN/TAMU, College Station

4. **Animal health effects** —
   Andy Cole, USDA-ARS

5. **Technology transfer** —
   J. M. Sweeten, TAES; Bill Hargrove, KSU.
Quantify atmospheric losses
Reduce losses
Accurate emission factors
Animal health effects

NH$_3$
Odors/
Odorants
Dust/PM

N.A. Cole, USDA-ARS-CPRL
Experimental Facilities & Personnel

- **Air quality parameters involved:**
  - **Particulate matter (PM)** — TAES/Amarillo, BAEN/Texas A&M, BAEN/Kansas State.
  - **Odor/olfactometry** — WTAMU
  - **Odorous gases** — TAES/Amarillo
  - **Ammonia** — USDA-ARS/Bushland & Watkinsville GA; TAES-AMA; BAEN/CLL.
  - **Hydrogen Sulfide** — TAES/AMA; WTAMU; BAEN/CLL.
  - **VOCs** — TAES/AMA;
  - **R-VOCs** — BAEN/CLL.
Experimental Facilities

- **Experimental feedlots**
  - TAES/ARS, Bushland—385 head capacity
  - WTAMU—600 head capacity

- **Commercial feedyards—40,000+ hd**
  - Texas Panhandle (3)
  - SW Kansas

- **Commercial dairies—2,000 hd. capacity**
  - N. Central Texas (2)
Objective 1 – Emissions Measurement/Odor

Characterize ambient odor concentrations & odor emissions from open-lot feedyards  
(Parker & Rhoades, WTAMU)
## Dynamic Olfactometry--Summary

Odor Concentrations, ODT (OU/m³ or OU)  
3 beef cattle feedyards, 12-month period  
(Parker & Rhoades, WTAMU)

<table>
<thead>
<tr>
<th>Location</th>
<th>n</th>
<th>Mean ODT</th>
<th>Range ODT</th>
<th>Median ODT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upwind</td>
<td>136</td>
<td>40</td>
<td>7 - 362</td>
<td>23</td>
</tr>
<tr>
<td>Downwind Feed Pens</td>
<td>136</td>
<td>59</td>
<td>8 – 665</td>
<td>25</td>
</tr>
<tr>
<td>Downwind Holding Pond</td>
<td>136</td>
<td>78</td>
<td>8 - 1223</td>
<td>25</td>
</tr>
</tbody>
</table>
**Obj. 1 – Emissions Measurement--H₂S**
(Parker & Rhoades, WTAMU)

Ambient **H₂S Concentrations (ppm)** Immediately Downwind of Feed Pens and Runoff Holding Ponds, Feedyards A, B, C (n=3).

<table>
<thead>
<tr>
<th>Location</th>
<th>Mean</th>
<th>SD</th>
<th>No. obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upwind, background</td>
<td>0.007</td>
<td>0.014</td>
<td>120</td>
</tr>
<tr>
<td>Downwind:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* pens</td>
<td>0.025</td>
<td>0.023</td>
<td>118</td>
</tr>
<tr>
<td>* holding pond</td>
<td>0.038</td>
<td>0.109</td>
<td>114</td>
</tr>
</tbody>
</table>
NH₃, H₂S & VOCs flux measurements,
Feedyard C
(Koziel, Baek, Spinhirne, TAES-AMA; Todd & Cole, USDA-ARS)

Flux-Chamber methods vs. Micromet.-based methods
Ammonia Lasers at Feedyard C
(Todd & Cole, USDA-ARS)
Ammonia concentrations decreased approximately 72-134 ug per 100 meters.
Ammonia concentrations decreased approximately 71-436 ug per 100 meters
Daily Ammonia Flux, Feedyard C, Summer 2003

Todd & Cole, USDA-ARS/Bushland

Mean Daily Flux = 34 ug m$^{-2}$ s$^{-1}$

Mean = 2240 kg NH$_3$-N d$^{-1}$
<table>
<thead>
<tr>
<th>Trial</th>
<th>No. Days</th>
<th>Daily Flux</th>
<th>NH$_3$-N Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer '02</td>
<td>4</td>
<td>16</td>
<td>1030</td>
</tr>
<tr>
<td>Winter '03</td>
<td>7</td>
<td>8</td>
<td>520</td>
</tr>
<tr>
<td>Summer '03</td>
<td>10</td>
<td>34</td>
<td>2240</td>
</tr>
</tbody>
</table>
NH$_3$-N and H$_2$S-S flux vs. manure pack temperature. flux chamber (Koziel, Baek, Spinhirne, TAES-AMA)
Diurnal variations of NH$_3$-N and H$_2$S-S flux from cattle pens (Koziel, Baek, et al., TAES-AMA)
**NH₃-N & H₂S-S : Conc. & Emission Rates**

**Feedyard C (NCSU flux chamber; one cattle pen)**

*(Koziel, Baek, Spinhirne, TAES-AMA)*

<table>
<thead>
<tr>
<th>Period</th>
<th>NH₃, ppm</th>
<th>H₂S, ppb</th>
<th>NH₃-N g/hd/day</th>
<th>H₂S-S-S g/hd/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer, 2002</td>
<td>16 (1.3-97.0)</td>
<td>10 (1.1-77.6)</td>
<td>35</td>
<td>0.027</td>
</tr>
<tr>
<td>Winter, 2002</td>
<td>3 (0.6-15.8)</td>
<td>2 (0.1-34.5)</td>
<td>9</td>
<td>0.006</td>
</tr>
<tr>
<td>Spring, 2003</td>
<td>20 (1.2-99.0)</td>
<td>9 (0.5-50.4)</td>
<td>31</td>
<td>0.026</td>
</tr>
</tbody>
</table>
## Mean NH₃-N and H₂S-S flux (µg/m²/sec)

### NCSU Flux Chamber, Feedyard C

*Flux, as % of N and S fed in cattle ration:*

- NH₃-N ~16%
- H₂S-S ~ 0.14%

<table>
<thead>
<tr>
<th>Period Phase</th>
<th>NH₃-N flux</th>
<th>H₂S-S flux</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>(SD)</td>
</tr>
<tr>
<td>Summer 2002*</td>
<td>28</td>
<td>(27)</td>
</tr>
<tr>
<td>Winter 2003</td>
<td>5</td>
<td>(4)</td>
</tr>
<tr>
<td>Spring 2003</td>
<td>30</td>
<td>(25)</td>
</tr>
</tbody>
</table>
**Ambient Concentrations of H$_2$S and NH$_3$ -- Feedyard C, Texas Panhandle**

*(Koziel, Baek, Spinhirne, TAES-AMA)*

- 1.5 m above ground level, ~fence-rail height.
- 3 measurements / hr (10 min each), used last 3 min. data
- Continuous NH$_3$ and H$_2$S analyzers
- On-site laboratory
- EPA grade calibration gases.
## Ambient NH₃ and H₂S Concentrations (ppbv), Feedyard C  
*(Koziel, Baek, Spinhirne, TAES-AMA)*

<table>
<thead>
<tr>
<th>Season</th>
<th>Number of Measurement Days</th>
<th>Hourly averaged NH₃ concentrations (ppb)</th>
<th>Hourly averaged H₂S concentrations (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean (st. dev.)</td>
<td>Min - Max</td>
</tr>
<tr>
<td>Fall 2002</td>
<td>10</td>
<td>429 (507)</td>
<td>106 - 2,890</td>
</tr>
<tr>
<td>Winter 2003</td>
<td>14</td>
<td>475 (409)</td>
<td>108 – 2,280</td>
</tr>
<tr>
<td>Spring 2003</td>
<td>15</td>
<td>712 (686)</td>
<td>2 – 5,270</td>
</tr>
</tbody>
</table>
Obj. 1--Significant Findings, Years 1 & 2

- **Odor concentrations**
  - ODT varied widely;
  - Wet weather increased ODT.

- **Ammonia flux from cattle feedyard**
  - NH₃ & H₂S emissions increased with temperature.
    - Diurnal patterns—winter & summer;
  - NH₃ ~1000 X H₂S emissions.
  - Similar values for flux gradient (ARS) vs. flux chamber (TAES) methods @ Feedyard C.
  - Flux chamber methods were improved.
Season vs. Manure Layer Effect on NHx

(Todd & Cole, USDA-ARS, Bushland TX)
Estimating Maximum N Volatilization Using N:P Ratios

- The lower N:P ratio of pen surface manure, compared to the diet, is a measure of maximum N volatilization losses.
- Change from pen surface to compost – estimate of compost losses.

Cole & Todd. USDA-ARS-CPRL
**Summertime VFA flux from cattle pens**

**NCSU Flux Chamber** *(Koziel, Baek, Spinhirne, TAES-AMA)*

<table>
<thead>
<tr>
<th>Volatile Fatty Acids (VFA)</th>
<th>Concentration Mean, ppb</th>
<th>Concentration Range, ppb</th>
<th>Mean flux (µg/m²/min) (+/-Std)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>47</td>
<td>35 – 55</td>
<td>12.1 (2.3)</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>23</td>
<td>17 – 26</td>
<td>7.2 (1.3)</td>
</tr>
<tr>
<td>Isobutyric acid</td>
<td>10</td>
<td>7 – 13</td>
<td>3.8 (1.0)</td>
</tr>
<tr>
<td>Butyric acid</td>
<td>13</td>
<td>10 – 15</td>
<td>5.0 (0.9)</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>5.6</td>
<td>3.9 – 6.5</td>
<td>2.5 (0.5)</td>
</tr>
<tr>
<td>Valeric acid</td>
<td>6.2</td>
<td>3.8 – 8.4</td>
<td>1.7 (0.6)</td>
</tr>
<tr>
<td>Hexanoic acid</td>
<td>0.66</td>
<td>0.43 – 0.81</td>
<td>0.3 (0.1)</td>
</tr>
</tbody>
</table>

**Flux comparison:**
- Hydrogen sulfide = 1.28 (+/- 1.06)
- Ammonia = 1,666 (+/- 1,642)
MDGC-MS-O analysis of odor samples collected with SPME (Koziel, TAES-AMA)

Separated components of livestock odor
Analysis of beef cattle odor (Aromagrams)

- p-ethyl-phenol
- p-cresol
- isovaleric acid
- butyric acid
- DMTS
- acetic acid
- methyl mercaptan
- trimethyl amine
Obj. 1--Significant Findings, Years 1 & 2

- **VOC’s--GC/MS/SPME**
  - 30+ detected
  - including VFA’s.

- **Multidimensional olfactometry vs. GC/MS—”Aromagrams”**
  - Odorants changed with distance downwind of feedyard.
  - Major constituents of downwind odor—
    - p-cresol
    - p-ethyl phenol
    - Isovaleric acid.

- **Ammonia reduction w/ surface-applied urease inhibitor:**
  - ~50+ % in vitro/lab;
  - ~ 0 % in preliminary field tests.
Objective 2. Cattle Feedlot Dust (PM) Emissions

- Diurnal pattern, PM.
- Hot dry weather; evening/night cooling.
- Cattle aggressive activity ~2 hrs sunset.
- Inversion conditions.
Objective 2: Abatement Measures
Maghirang, KSU; Auvermann, TAES/TAMU

Weight Drop Test Chamber

4.5 kg steel weight

Base soil  PM$_{10}$ samplers
Objective 2--Abatement Measures/PM
Weight Drop Test Chambers (TAES/TAMUS & KSU)

**WDTC results:**
* Loose, **dry manure @ 1, 2 or 4” depth**
* At given impact energy & moisture:
  * PM$_{10}$ increased with depth.

**Recommendation**—>frequent scraping!!
* Greatest benefit: 2” $\rightarrow$ 1”
* Marginal benefit: 4 “ $\rightarrow$ 2
Objective 2 -- Abatement Measures/PM

Weight Drop Test Chambers

(Auvermann, TAES/TAMUS; Maghirang & Murphy, KSU)

- **Moisture content vs. PM$_{10}$ emission, mg.**

- **Test conditions:**
  - 3 reps.
  - 10 cm depth
  - Drop energy = 54 J
  - 95% C.I.

- **Results:**
  - moisture is critical
  - $\sim$10 x increase in PM$_{10}$ from 20% $\rightarrow$ 6% MC.
Objective 2—PM Abatement Measures
(Auvermann & Marek, TAES/TAMUS-AMA)

How Much Water?

- Major upgrade to lysimetry system completed May 2004
- Real-time data
- Data already show diurnal effect of “hygroscopicity”
- Web-based control, datalogging and video monitoring
Objective 2—PM Abatement Measures
Feedlot Evaporation Rate (lysimetry)
(Auvermann et al., TAES-AMA)

- Surface manure moisture, summer
- Diurnal trend, summer.
  - Afternoon--
    - Rapid evaporation
    - Rising vapor pressure
    - Minimum ~ 9 pm.
  - Night--
    - Falling vapor pressure
    - Rising humidity
    - Hygroscopic adsorption.
Obj. 2--Significant Findings, Years 1 & 2

- **Particulate matter/”feedlot dust”**—
  - Intrinsic susceptibility increased with:
    - Simulated hoof energy –vertical mode
    - Greater manure depth
    - Decreased moisture content <20% w.b. (10x increase).

- **Evaporation rates (lysimeters) —**
  - Winter ~ 50-70% of ETo.
  - Summer < 30% of ETo;
  - High evaporation rate -- daytime
  - Hygroscopic effects -- night/morning.
Obj. 2—Potential Chemical Mulches: MgCl\textsubscript{2} and Organic Polymer (X-hesion).
(Maghirang, KSU)

- The effectiveness of MgCl\textsubscript{2} and an organic-based polymer (X-hesion) was compared with that of water.
- The two materials were applied in accordance with manufacturers’ specifications.
- Drop tests involved 27 J of drop energy and 10 cm manure depth.

![Images showing MgCl\textsubscript{2} and H\textsubscript{2}O after 1 h and 48 h.]
MgCl$_2$ and Organic Polymer (X-hesion), con’t.

- Manure treated with MgCl$_2$, X-hesion, & water did not differ in PM$_{10}$ emission immediately after application.
- As the wet surface manure layer dried up, however, the manure with X-hesion had the least PM$_{10}$ emission and the manure with MgCl$_2$ had the greatest emission.
Objective 2—PM Abatement Measures

- **Frequent manure harvesting/scraping** *—reduce depth.
- **Sprinkler irrigation** *—replace evaporative demand.
  - Water requirement ~> cattle drinking water needs.
  - Scheduling vs. moisture balance/ET data.
- **Cattle stocking density** —excreted moisture, smaller area.
- **Water curtain** —Edge-of-feedlot sprinkler/“scrubber”.
- **Mulches**—physical, chemical, etc.?

* Denotes USDA-NRCS- **EQIP/TX cost-share practices**, 2003-05.
Objective 3– Scientific Basis for Emission Factors

- Biological & Agricultural Engineering Dept., TAMU
  - Calvin Parnell
  - Bryan Shaw
  - Ron Lacey
  - Saqib Mukhtar
  - Sergio Capereda
- Center for Agricultural Air Quality Engineering Science, TAMUS
  - Co-located PM$_{10}$ and TSP samplers
Emission Factors

- Development of Cattle Feed Yard Fugitive Dust Emission Factors
  - 280 lbs/1000hd-day (TSP)
    - Peters and Blackwood, 1977
    - Algeo data with infinite line source model
  - 70 lbs/1000hd-day (PM$_{10}$)
    - Sweeten et al, 1988
    - PM$_{10}$/TSP ratio = 25%
  - 10 lbs/1000hd-day (PM10)
    - Parnell, S. 1994
  - 15 lbs/1000hd-day (PM$_{10}$)
    - Parnell et al, 1999
    - Source sampling
Emission Factor Development Protocol
(Parnell et al., TAMU)

- Source sampling at a Texas feed yard
  - 5 Co-located TSP/PM$_{10}$ Samplers
  - 2 TEOM Samplers
  - Tower with TSP samplers at 5, 7, and 9m
  - Met Station

- ISCST3
  - TSP Measured Concentrations
  - Met Data

- PSD Data to Correct TSP to PM$_{10}$
TEOM 1-hr Concentrations

Date and Time

micrograms per cubic meter

1-hr Concentrations

7/14/03 22:50:05, 502.9
7/15/03 22:50:05, 792.9
7/16/03 22:50:05, 507.9

7/14/03 22:50:05, 502.9
7/15/03 22:50:05, 792.9
7/16/03 22:50:05, 507.9
Obj. 3--Significant Findings—Years 1 & 2

- **Summer PM emissions**—
  - Diurnal patterns
  - Evening/nighttime peaks ~ 10-20 X daytime concentrations.
  - Nighttime PM emission peaks— influenced by inversion conditions (“fanning”).
  - Low moisture + cattle activity + inversions.
  - Rainfall— reduces PM emission & lowers TSP/ PM\textsubscript{10} ratio.

- **Dispersion model comparison**
  - Compared back-calculated emission flux from concentration data
  - ISC Model (Gaussian) vs. bLS (Euolarean) ~ 10 X differences
  - Cannot mix-and-match methodologies.

- **Development of accurate emission factors**
  - PM, NH\textsubscript{3}, H\textsubscript{2}S, VOC, odor.
  - continuing for open-lot feedlots & dairies
Dairy NH₃ sampling for Emission factor development, Muhktar, BAEN/TAMU
<table>
<thead>
<tr>
<th>GLAS</th>
<th>Samples</th>
<th>Conc. (ppm)</th>
<th>Flux (µg/m²/s)</th>
<th>ER (kg/day)</th>
<th>GLAS Temp. °C</th>
<th>Amb. Temp. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>11</td>
<td>1.9 ±1.6b</td>
<td>0.81 ±0.7b</td>
<td>1.17 ±0.97b</td>
<td>43.17 ±7.1b</td>
<td>33.34 ±1.6b</td>
</tr>
<tr>
<td>Freestall</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-feed</td>
<td>5</td>
<td>57.5 ±50.5</td>
<td>20.53 ±23</td>
<td>4.79 ±5.4</td>
<td>25.79 ±3.16</td>
<td>33.38 ±1.33</td>
</tr>
<tr>
<td>Feed</td>
<td>5</td>
<td>74.0 ±72.4</td>
<td>31.75 ±31</td>
<td>8.48 ±8.3</td>
<td>33.91 ±56.1</td>
<td>34.60 ±0.2</td>
</tr>
<tr>
<td>Bedding</td>
<td>2</td>
<td>2.4 ±22.2</td>
<td>1.05 ±9.5</td>
<td>0.34 ±3.1</td>
<td>27.02 ±2.78</td>
<td>33.34 ±3.14</td>
</tr>
<tr>
<td>Water</td>
<td>2</td>
<td>21.7 ±84.4</td>
<td>9.30 ±36.2</td>
<td>0.16 ±0.63</td>
<td>23.79 ±2.07</td>
<td>34.53 ±2.76</td>
</tr>
<tr>
<td>Open Lot</td>
<td>8</td>
<td>4.8 ±3.9</td>
<td>2.05 ±1.7</td>
<td>6.72 ±5.5</td>
<td>30.63 ±3.5</td>
<td>33.27 ±1.43</td>
</tr>
<tr>
<td>Crowding</td>
<td>4</td>
<td>9.6 ±8.2</td>
<td>4.06 ±3.4</td>
<td>0.32 ±0.3</td>
<td>21.54 ±1.0</td>
<td>25.62 ±1.0</td>
</tr>
<tr>
<td>Sep. Solids</td>
<td>4</td>
<td>3.7 ±7.2</td>
<td>1.50 ±2.9</td>
<td>0.01 ±0.03</td>
<td>34.01 ±5.2</td>
<td>-</td>
</tr>
<tr>
<td>Lagoon 1</td>
<td>8</td>
<td>32.8 ±7.1</td>
<td>14.09 ±3.0</td>
<td>23.4 ±5</td>
<td>29.48 ±1.2</td>
<td>29.61 ±2.3</td>
</tr>
<tr>
<td>Lagoon 2</td>
<td>6</td>
<td>28.1 ±2.9</td>
<td>12.07 ±1.3</td>
<td>17.72 ±1.9</td>
<td>28.42 ±0.7</td>
<td>26.67 ±1.9</td>
</tr>
</tbody>
</table>

Statistic 55a

a Summation, b 95% confidence interval (CI)
Continuous Monitoring of PM (Auvermann, TAES-AMA)
Objective 4. Animal Health Effects

Dust/PM Exposure Chambers
Objective 4 – Animal Health Effects

(Cole, ARS; Auvermann, TCE/TAES; Brown/Loneragan, WTAMU; Pickrell, KSU)

- PM exposure chambers for incoming calves
  - Prototype—designed & built.
  - Calibrated for PM$_{2.5}$ delivery.
  - Test chambers constructed.

- Cattle exposure experiments → Year 3

- Feeding trials — calf performance & health effects indicators (Brown & Loneragan, WTAMU; Pickrell, KSU).

- Health effect indicators --
  - Blood antioxidant (Chirase, TAES)
  - Lung lavage fluids (Pickrell, KSU)
Objective 5 – Technology Transfer

- **Project Industry Advisory Committee**
  - TCFA & KLA

- **QA/QC plan developed.**

- **Graduate students ~ 30 involved with project.**

- **Scientific outputs, to August ‘04:**
  - > 60 professional papers.
  - > 10 refereed journal articles, published or subm.
  - > 50 presentations at scientific meetings; etc.

- **Co-funding recruited > $ 2 million to date.**