Cattle Housing Integrated Research Project: Current Results, Future Plans

Erin Cortus

South Dakota State University
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- Stakeholder Advisory Group
- Cooperating Producers

- Project Participants:

  South Dakota State University
  • Erin Cortus
  • Dick Nicolai
  • Steve Pohl
  • Graduate and Undergraduate Students
  • Technical Staff

  USDA-ARS Meat Animal Research Center
  • Mindy Spiehs
  • Technical Staff

  Iowa State University Extension and Outreach
  • Beth Doran
  • Kris Kohl
  • Angie Rieck-Hinz

  Livestock and Poultry Environmental Learning Center
  • Leslie Johnson
  • Jill Heemstra
  • Rick Stowell
Presentation Objectives

• Why did we do this?
• What did we find out?
  ▪ What does this mean for barn management and design?
• What is next?
WHY DID WE DO THIS?
Bedded Mono-Slope Barns

- East-west orientation with southern exposure
- Natural ventilation
- Curtain-sided
- Stocking density: 38-50 sq ft/animal
- Manure and bedding management varies widely
- Bedding added 1-2 times/week
- Many different bedding materials used
Extreme Weather Conditions

Temperature, F

Spring Summer Fall Winter Spring Summer Fall Winter

Scrape A  Scrape B  Pack A  Pack B
Factors that Affect Gas and Dust Production in Livestock Facilities

• Climatic Environment
  - Temperature/Humidity
  - Air velocity/Airflow

• Animals
  - Diet
  - Number and size
  - Activity

• Building and Manure Management
  - Manure properties
  - Bedding properties
  - Storage and removal
Factors that Affect Gas and Dust Production in Livestock Facilities

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  ▪ Manure properties
  ▪ Bedding properties
  ▪ Storage and removal
Air Quality Concerns

• Related to Regulations
  ▪ Ammonia
  ▪ Particulate matter
• Related to Cattle Production
  ▪ Time of day
  ▪ Seasonal effects
• “Are we doing it right?”
HOW DID WE DO THIS?
Purpose of Air Quality Grant

• Gather baseline emission data from beef confinement barns
• Evaluate 2 manure handling systems
Monitoring Methodology

- Two mobile instrument shelters
- Each mobile instrument rotated between two barns in South Dakota or Iowa
- Collected data for one month each season from each barn for two years
WHAT DID WE FIND OUT?
Airflow Assumptions

South Wall Opening Airflow = Perpendicular Velocity x Area

North Wall Opening Airflow = Perpendicular Velocity x Area

Assuming constant air density:
Building Airflow = South Wall Opening Airflow = North Wall Opening Airflow
Concentration & Emission Assumptions

\[
\text{Emission} = \text{Airflow} \times (\text{Outlet Air Concentration} - \text{Inlet Air Concentration})
\]

Airflow Direction is Irrelevant
Monitoring Air Quality in Barns

- Barn environment sampling
  - Temperature/RH
  - Airspeed

- Eight gas sampling points
  - Ammonia
  - Hydrogen sulfide
  - Methane
  - Carbon dioxide
  - Nitrous oxide

```
East Side View

4, 8

1, 2, 3, 5, 6, 7

Feed bunk

Foundation
```

```
North Side View

Pen 1

4

1, 2, 3

5

8

Pen 2

1

2

3

6

7

Roof

Foundation
```
Monitoring Particulate Matter (Dust)

• Scrape Systems
  ▪ Measured using Minivols
  ▪ Collected baseline emission data

• Pack Systems
  ▪ Measured using Lo-Vol Particulate Air Samplers
  ▪ Evaluated concentration relative to management events
North-side adjustable wall.

Covered feeder alley

South side, permanently open wall.

Manure storage alley.

Air quality sensor package
Monitoring Weather

- On-site weather station measured
  - Wind direction
  - Wind speed
  - Ambient air temperature
  - Relative humidity
Example of Changing Airflow Conditions Over 24-h

**Airflow Out of the South Wall**

- Y-axis: Airflow, m³/s

**Ammonia Concentration at the South Wall (Green) and North Wall (Red)**

- Y-axis: Conc, ppb

**Ammonia Emission**

- Y-axis: Emission, kg/d

- X-axis: Time in hours
Air Flow

Air Speed

Gas Concentration

C_{Outlet}

C_{Inlet}

Air Speed

Gross = Q \cdot C_{Outlet}

Net = Q \cdot (C_{Outlet} - C_{Inlet})

Net = Q \cdot (C_{Outlet} - C_{Inlet})

Air Speed
Airflow – Revised Assumption

South Wall Opening Airflow = Perpendicular Velocity x Area

North Wall Opening Airflow = Perpendicular Velocity x Area

South Wall Opening Airflow ≠ North Wall Opening Airflow

New Assumption:
North Wall Opening Airflow Better Represents Body of Air That Is Picking up Pollutants
Concentration and Emission – Revised Assumptions

Net Emission = North Wall Opening Airflow x (North Wall Concentration – South Wall Concentration)

Gross Emission = North Wall Opening Airflow x (Outlet Concentration)

Average Emission Rate is Between Gross Emission Rate and Net Emission Rate

Southerly Wind Emission Rate = Northerly Wind Emission Rate
WHAT DID WE FIND OUT – ABOUT THE ENVIRONMENT?
# Average Temperatures, °F

<table>
<thead>
<tr>
<th>System</th>
<th>Closed</th>
<th>Open</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Barn</td>
<td>Ambient</td>
</tr>
<tr>
<td>Scrape A</td>
<td>30</td>
<td>27</td>
</tr>
<tr>
<td>Scrape B</td>
<td>21</td>
<td>18</td>
</tr>
<tr>
<td>Pack A</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>Pack B</td>
<td>37</td>
<td>42</td>
</tr>
</tbody>
</table>
# Average Relative Humidity, %

<table>
<thead>
<tr>
<th>System</th>
<th>Closed</th>
<th></th>
<th>Open</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Barn</td>
<td>Ambient</td>
<td>Barn</td>
<td>Ambient</td>
</tr>
<tr>
<td>Scrape A</td>
<td>76</td>
<td>77</td>
<td>72</td>
<td>69</td>
</tr>
<tr>
<td>Scrape B</td>
<td>92</td>
<td>85</td>
<td>77</td>
<td>75</td>
</tr>
<tr>
<td>Pack A</td>
<td>78</td>
<td>82</td>
<td>65</td>
<td>68</td>
</tr>
<tr>
<td>Pack B</td>
<td>77</td>
<td>71</td>
<td>61</td>
<td>66</td>
</tr>
</tbody>
</table>
Average Airflow Through Barns in Relation to Ambient Air Speed

<table>
<thead>
<tr>
<th>Curtain Opening</th>
<th>Average airflow @ 11 mph† ambient air speed in the north wall opening, air changes per hour</th>
<th>Air Changes Per Hour / mph Wind‡</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scrape A</td>
<td>Scrape B</td>
</tr>
<tr>
<td>&lt; 5 ft</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>&gt; 5 ft</td>
<td>153</td>
<td>163</td>
</tr>
</tbody>
</table>

† Based on average hourly mean airflow measured in the north wall opening during the study at 11 mph airspeed perpendicular and into the south wall opening (northerly flow). Airspeed measured at the top of the weather tower.

‡ Assumes airflow through the barn linearly increases with increasing airspeed.
What Does This Mean?

• No appreciable temperature or humidity lift between ambient and barn air temperature
• Curtain position impacts the air through barn
• Variable wind direction and speed patterns in the south wall opening
WHAT DID WE FIND OUT – ABOUT GAS AND DUST CONCENTRATIONS?
Factors that Affect Gas and Dust Production in Livestock Facilities

- Climatic Environment
  - Temperature/Humidity
  - Air velocity/Airflow

- Animals
  - Diet
  - Number and size
  - Activity

- Building and Manure Management
  - Manure properties
  - Bedding properties
  - Storage and removal
Seasonal Mean Hourly Maximum Ammonia Concentrations

- **Pack Systems**
- **Scrape Systems**

![Graph showing the relationship between Average Temperature (F) and Average Maximum Concentration (ppm) for Pack and Scrape Systems.](image-url)
Seasonal Mean Hourly Maximum Ammonia Concentrations

\[ y = 0.0488x + 0.5731 \]

\[ R^2 = 0.2029 \]

\[ p < 0.1 \text{ (Slope)} \]
Seasonal Mean Hourly Maximum Hydrogen Sulfide Concentrations

![Graph showing the relationship between average maximum concentration and average temperature for Pack Systems and Scrape Systems.](image-url)
Seasonal Mean Hourly Maximum Hydrogen Sulfide Concentrations

- **Pack Systems**
  
  \[ y = 5.512x - 147.39 \]
  
  \[ R^2 = 0.6303 \]
  
  \[ p < 0.01 \] (Slope)

- **Scrape Systems**
  
  \[ y = 0.697x - 8.219 \]
  
  \[ R^2 = 0.6159 \]
  
  \[ p < 0.01 \] (Slope)
Seasonal Mean Hourly Maximum Hydrogen Sulfide Concentrations for Pack Systems

Graph showing the relationship between average temperature and average maximum concentration for Pack System 1 and Pack System 2.
Average Hourly Mean Ammonia Concentration as influenced by Time of Day

![Graph showing ammonia concentration by time of day for Scrape A, Scrape B, Pack A, and Pack B.](image)
Average Hourly Mean Hydrogen Sulfide Concentration as influenced by Time of Day

Scrape A
Scrape B
Pack A
Pack B

Concentration, ppb
Hour of the Day

Concentration, ppb
0 50 100 150 200 250
0 2 4 6 8 10 12 14 16 18 20 22

Hour of the Day
0 2 4 6 8 10 12 14 16 18 20 22
### Average Concentrations, ppb

<table>
<thead>
<tr>
<th>Gas</th>
<th>Scrape A</th>
<th>Scrape B</th>
<th>Pack A</th>
<th>Pack B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>2100</td>
<td>2500</td>
<td>2100</td>
<td>3800</td>
</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>27</td>
<td>23</td>
<td>103</td>
<td>80</td>
</tr>
</tbody>
</table>

For Comparison:

Ammonia
• Over Feedlots in Texas – 1500 to 3000 ppb (Todd et al., 2005)

Hydrogen Sulfide:
• Center of Feedlots in Nebraska – 2 to 37 ppb (Koelsch et al., 2004)
Factors that Affect Gas and Dust Production in Livestock Facilities

- Climatic Environment
  - Temperature/Humidity
  - Air velocity/Airflow
- Animals
  - Diet
  - Number and size
  - Activity
- Building and Manure Management
  - Manure properties
  - Bedding properties
  - Storage and removal
Particulate Matter
Routine Operation vs. Bedding Event
Total Suspended Particles
April 28 - May 5, 2011

<table>
<thead>
<tr>
<th>Date</th>
<th>Concentration (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/27/2011</td>
<td></td>
</tr>
<tr>
<td>4/28/2011</td>
<td></td>
</tr>
<tr>
<td>4/29/2011</td>
<td></td>
</tr>
<tr>
<td>4/30/2011</td>
<td></td>
</tr>
<tr>
<td>5/1/2011</td>
<td></td>
</tr>
<tr>
<td>5/2/2011</td>
<td></td>
</tr>
<tr>
<td>5/3/2011</td>
<td></td>
</tr>
<tr>
<td>5/4/2011</td>
<td></td>
</tr>
<tr>
<td>5/5/2011</td>
<td></td>
</tr>
<tr>
<td>5/6/2011</td>
<td></td>
</tr>
</tbody>
</table>

Bedding Event
Prevailing South wind

Bedding Event
Prevailing North wind

Position 1
Position 2
Position 3
Position 4
Position 5
Position 6
Total Suspended Particles
June 23 - July 1, 2011

Bedding Event
Wind changed direction during sampling

Bedding Event
Slight south wind

Date
Concentration (µg/m³)

Position 1
Position 2
Position 3
Position 4
Position 5
Position 6

North Side
South Side
<table>
<thead>
<tr>
<th></th>
<th>Pack Barn A</th>
<th></th>
<th>Scraper Barns</th>
<th>Open Feedlot†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Routine Operation</td>
<td>Bedding Event</td>
<td>Barn A</td>
<td>Barn B</td>
</tr>
<tr>
<td>TSP (µg/m³)‡</td>
<td>58.6</td>
<td>702.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂.₅ (µg/m³)‡</td>
<td>4.9</td>
<td>29.7</td>
<td>10.0</td>
<td>14.1</td>
</tr>
<tr>
<td>PM₁₀ (µg/m³)‡</td>
<td>17.5</td>
<td>141.7</td>
<td>25.3</td>
<td>28.0</td>
</tr>
<tr>
<td>PM₂.₅/TSP (%)</td>
<td>4.4</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₁₀/TSP (%)</td>
<td>16.1</td>
<td>12.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂.₅/PM₁₀ (%)</td>
<td>21.1</td>
<td>19.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Algeo et al., 1972, Sweten et al., 1988, Sweeten et al., 1998, Purdy et al., 2007, and Guo et al., 2011
†‡ Significant difference (P < 0.05) between Pack Barn A Routine Operation and Pack Barn A Bedding Event
What Does This Mean?

- Variability with a Pack system environment for gas production
- Largest influence of temperature on hydrogen sulfide
- Time of day
- Relatively low particulate matter concentrations
- Short periods of elevated dust during the bedding events
WHAT DID WE FIND OUT – ABOUT GAS EMISSIONS?
Emission Rate Calculation & Presentation

- **Conditions**
  - Open Curtain (Warmer)
  - Closed Curtain (Cooler)

- **Method of Calculation**
  - ADM – Average of Daily Mean Emission Rates
  - SNM – For South Wind, Average Combination of Airflow and Concentration

- **Type of Emission**
  - Gross Emission Rate
  - Net Emission Rate
Ammonia Emission Rate Ranges (based on gross and net emission rates)

- Emission, kg per head space per day
- Emission, lb per head space per day

<table>
<thead>
<tr>
<th>Scrape</th>
<th>Open</th>
<th>Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scrape A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scrape B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pack A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pack B</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Emission rates are shown for different scenarios and conditions, indicating variations in ammonia emission rates.
Hydrogen Sulfide Emission Rate Ranges (based on gross and net emission rates)
Factors that Affect Gas and Dust Production in Livestock Facilities

• Climatic Environment
  ▪ Temperature/Humidity
  ▪ Air velocity/Airflow

• Animals
  ▪ Diet
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  ▪ Activity

• Building and Manure Management
  ▪ Manure properties
  ▪ Bedding properties
  ▪ Storage and removal
What Does This Mean?

• Lower emissions under closed \textit{curtain} conditions
  – Temperature and airspeed/airflow
• Higher \textit{variability} in emissions with pack system
• \textit{Relationship} between gas and dust concentration and emission
Products Available

• Factsheet: “Air Quality in Bedded Mono-slope Beef Barns”
• Webinars
  – Mono-slope Beef Barn Design and Management
  – Results of the Mono-slope Beef Barn Research Project
• Beef Facilities Conference Proceedings and Recordings

extension.org/
WHAT’S NEXT?
What’s Next For Us?

Based on this research, and research by others:

• Why do these barns do what they do?
• Can we accurately predict what they will do in other barns?
• How can we positively change what they do?

= Modeling
Proposal: Comparison of economic and environmental factors for North Central Region beef cattle housing options

- Quantify the sustainability of production systems and alternative scenarios through the use of an existing process-based, life cycle analysis model (Integrated Farm System Model)
- Verify against data from NCR cattle production systems and management practices

- Project Components:
  - Advisory group
  - Nutrient mass balances from various facilities
  - Nutrient management plan data exercise
  - Adapt IFSM model
  - Forecasts for scenarios
  - Result dissemination
What’s Next For You?

• Short-term and long-term decision-making
• Promote continued research
  ▪ Cooperators
  ▪ Stakeholder committee members
  ▪ Share with public officials

Ask Questions!!