AIR QUALITY in Bedded Mono-Slope Beef Barns

Background

Bedded mono-slope barns are becoming more common in the upper Midwest. The primary reason producers are building these facilities is to control manure runoff. Other reasons include: to improve animal comfort and performance (especially in periods of inclement weather), to capture more value from the manure, and to reduce the potential for animal sickness.

Because bedded mono-slope beef barns are relatively new, little research has been published regarding important factors such as environmental quality, building management and animal performance. As a result, in 2010 a group of researchers and Extension specialists from South Dakota State University, U.S. Meat Animal Research Center, Iowa State University, and University of Nebraska-Lincoln were awarded a grant from the USDA National Institute of Food and Agriculture to investigate air quality in this style of barn.

The research had three objectives: 1) to gather baseline data for the levels of gas emissions and particulate matter (PM) from bedded mono-slope beef barns, 2) to evaluate the effect of two different manure handling systems (Pack and Scrape) on air quality, and 3) to provide information about building and management practices that may reduce gas emissions.

Air Quality Research Methods

The study measured emissions of gases and PM from four mono-slope beef-finishing barns—two in northeast South Dakota and two in northwest Iowa. All barns were 100 feet wide. Pen density ranged from 35 to 43 square feet per head. In two barns, the bunk aprons and edges surrounding the pack were scraped weekly. Bedding was added to the pack, and the pack remained in the pen until the cattle were marketed. This manure handling system is referred to as Pack. The other two barns removed all bedding material and manure weekly. This system is referred to as Scrape.

Environmental conditions, including temperature, relative humidity and air speed, were monitored in the north and south wall openings. These same conditions also were captured by a 33-foot weather tower near the barn.

Five gases—ammonia, hydrogen sulfide, methane, carbon dioxide and nitrous oxide—were measured for month-long periods in each barn during fall, winter, spring, and summer over a two-year period in the north and south wall openings. Three of these gases—ammonia, hydrogen sulfide and methane—are commonly associated with beef feedlots, and will be the focus of this fact sheet.

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PACK System

SCRAPE System

Particulate matter (dust) was measured over two five-day periods in April and June 2011 at one of the Pack barns. Total suspended particulate was captured, from which two sizes (measured in micrometers) of PM were measured—PM_{10}, which can enter the human esophagus, and $PM_{2.5}$, which can enter the human lung. Both sizes can cause serious adverse health effects. The PM measurements were taken either during hours of regular operation or during a bedding event. In the Scrape barns, 24-hour collections of PM_{10} and $PM_{2.5}$ occurred at least twice during each monitoring period between August 2010 and December 2011. The Scrape data were used to determine the relationship of pen density with PM concentration.

Baseline Data from the Research Project

GAS CONCENTRATIONS

Concentrations are a measure of the amount of a substance (i.e., gas or PM) in a volume of air (i.e., a barn). The measured concentrations are a result of gases already present in the ambient air plus gases produced by the animal, manure, and/or bedding. Gas concentrations in a barn can affect both animal and worker productivity, and are also related to the gas emissions to the surrounding environment. In comparison, seasonal average hydrogen sulfide concentrations in the center of open Nebraska feedlots ranged from 2 to 37 ppb (Koelsch et al., 2004). Ammonia concentrations over open Texas feedlots were approximately 1,500 ppb, and up to 3,000 ppb for stable air conditions (Todd et al., 2005). In this research, average concentrations of hydrogen sulfide, ammonia and methane (Table 1) were below human workplace thresholds (NIOSH, 2011) for hydrogen sulfide (10,000 ppb), ammonia (25,000 ppb), and methane (1,000,000 ppb).

Table 1. Average gas concentrations (ppb)

	Scrape A	Scrape B	Pack A	Pack B
Hydrogen Sulfide	27	23	103	80
Ammonia	2100	2500	2100	3800
Methane	9200	8100	6200	8000

Gas concentrations peaked between 7 and 9 a.m. and between 8 and 9 p.m. These times coincide with increased animal movement, animal urination, fecal elimination, and disruption of the manure or pack surface. The evening peak was slightly higher than the morning peak, likely due to increasing ambient temperature and animal activity throughout the day.

As airflow through the barn decreased, gas concentration in the barn increased—following typical air mixing patterns. For periods of southerly winds, higher concentrations were measured in the north wall opening that served as the air outlet. For northerly winds, the south wall opening was the outlet with higher gas concentrations. However, gas concentrations for the south side of the barns were, on average, higher than the north side for inlet or outlet conditions at comparable wind speeds. This implies mixing and backdrafting in the south wall opening for both northerly and southerly winds. The warmer air could be a part of the increase in gas concentrations as well, but the difference in temperature between the openings was minimal. Warmer air could contribute to part of the increase in gas concentrations as well, but the difference in temperature between the openings was minimal.

There was a significant increase in hydrogen sulfide concentration with increasing temperature for both the Pack and Scrape barns. However, the increase was greater and more variable for Pack versus Scrape. Similarly, ammonia concentration tended to increase with increasing temperature for the Pack barns.

PARTICULATE MATTER AND BEDDING EVENTS

Overall concentration of total suspended particulate (TSP), $PM_{2.5}$, and PM_{10} varied significantly between the three-hour bedding event and normal operation (Table 2). However, the ratios of $PM_{2.5}$, PM_{10}, and TSP did not differ between routine operation and bedding events, indicating that dust composition was constant. In general, the concentration of $PM_{2.5}$ and PM_{10} relative to TSP is less in deep-bedded barns than open feedlots.

Close up of the head of the particulate matter sampler

Bedding event

Table 2. Overall mean concentration and distribution of PM during routine operation and bedding events in pack barns

	Routine Operation	Bedding Event	P – value	Open Feedlot
TSP (μg/m³)	58.6 ± 3.9	702.2 ± 266.1	0.0040	201-654[a]
$PM_{2.5}$ (μg/m³)	4.9 ± 3.0	29.7 ± 4.6	0.0002	25-34[b]
PM_{10} (μg/m³)	17.5 ± 12.1	141.7 ± 18.9	0.0001	88-285[c]
$PM_{2.5}$/TSP (%)	4.4 ± 0.7	2.7 ± 1.0	0.1431	10.0[d]
PM_{10}/TSP (%)	16.1 ± 2.4	12.1 ± 3.2	0.3176	39.7-41.0[e]
$PM_{2.5}/PM_{10}$ (%)	21.1 ± 1.9	19.4 ± 2.6	0.5870	9.4-29.0[f]

TSP = total suspended particles
$PM_{2.5}$ = particulate matter ≤ 2.5 μg
PM_{10} = particulate matter ≤ 10 μg
TSP = total suspended particles
$PM_{2.5}$ = particulate matter ≤ 2.5 μg
PM_{10} = particulate matter ≤ 10 μg
[a] Algeo et al., 1972, Sweeten et al., 1988 and Guo et al., 2011
[b] Purdy et al., 2007 and Guo et al., 2011
[c] Sweten et al., 1988, Sweeten et al., 1998, Purdy et al., 2007, and Guo et al., 2011
[d] Guo et al., 2011
[e] Sweeten et al., 1988, Sweeten et al., 1998, and Guo et al., 2011
[f] Purdy et al., 2007 and Guo et al., 2011

Table 3. Mean concentration of upwind, downwind, and net PM during routine operation and bedding events

	Routine Operation	Bedding Event	P – value	Open Feedlot
Upwind TSP (μg/m³)	48.9 ± 7.3 132.1 ± 50.2 83.2 ± 54.4	73.7 ± 13.6 769.2 ± 93.9 695.5 ± 101.8	0.1204	
Downwind TSP (μg/m³)			0.0001	185-836[a]
Net TSP (μg/m³)			0.0001	201-654[b]

TSP = total suspended particulate

[a] Algeo et al., 1972, Sweeten et al., 1988, Sweeten et al., 1998 and Guo et al., 2011

[b] Algeo at al., 1972, Sweeten et al., 1988 and Guo et al., 2011

Upwind TSP concentrations were similar during routine operation and bedding events, but downwind concentrations were significantly higher during bedding events (Table 3). Because net TSP concentrations (downwind minus upwind) were higher during bedding events, this implies that the additional PM during a bedding event comes from the bedding material and bedding activity inside the barn. Downwind and net concentration of TSP in Pack mono-slope barns during routine operation is substantially lower than reported values for open feedlots, but slightly higher than open feedlots during a bedding event. However, bedding events in mono-slopes are short, and PM concentrations quickly return to baseline levels.

Management Factors Affecting Air Quality and Animal Comfort

BUILDING ORIENTATION

The majority of mono-slope barns are built with an east-west orientation to facilitate air movement through the building. In the summer, winds in the upper Midwest are predominantly from the south; in the winter, they are usually from the north. Increased airflow through the barn will decrease gas concentrations. The east-west orientation also provides maximum shade in the summer and maximum sun in the winter, which should enhance animal comfort.

PEN DENSITY (SQUARE FEET PER HEAD)

Pen density in bedded mono-slope barns ranges from 38-50 square feet per head (Doran, 2013) and may vary with pen flooring, animal size or type, and weather. Because incoming feeder cattle and some breeds are smaller in size, pen density may be smaller. In summer months when the weather is hotter and more humid, producers may increase square footage per head. However, minimum pen density is ultimately determined by bunk space. Current specifications (MWPS, 1987) for feeder space are 9 to 11 inches per head for 400 to 800 pound calves and 11 to 13 inches per head for 800 to 1,200 pound animals fed twice daily. Bunk space per head is doubled when animals are fed once a day.

In this study, as average weight of the cattle increased, PM_{10} concentration increased in the Scrape barns. Likewise, as the number of cattle (Figure 1) was increased in the barn, the concentration of PM_{10} increased. Hence, increasing the square footage per animal may be one means to reduce PM.

BEDDING

Several bedding factors have the potential to influence air quality and animal comfort. Finely ground bedding absorbs more moisture than medium- or coarsely-ground bedding particles (Spiehs et al., 2013a). The type of bedding material also affects moisture absorption. Corn stover may be the best choice when considering a bedding material that can absorb a lot of moisture, but can also quickly evaporate that water.

Another study (Spiehs et al., 2013b) compared the potential for odor and E. coli production in wood and crop-based bedding materials. Pine wood shavings had the lowest odor activity value and the lowest *E. coli* concentration, whereas corncobs and shredded newspaper had the highest potential for odor. Wheat straw, switch grass, bean stover, and corn stover were

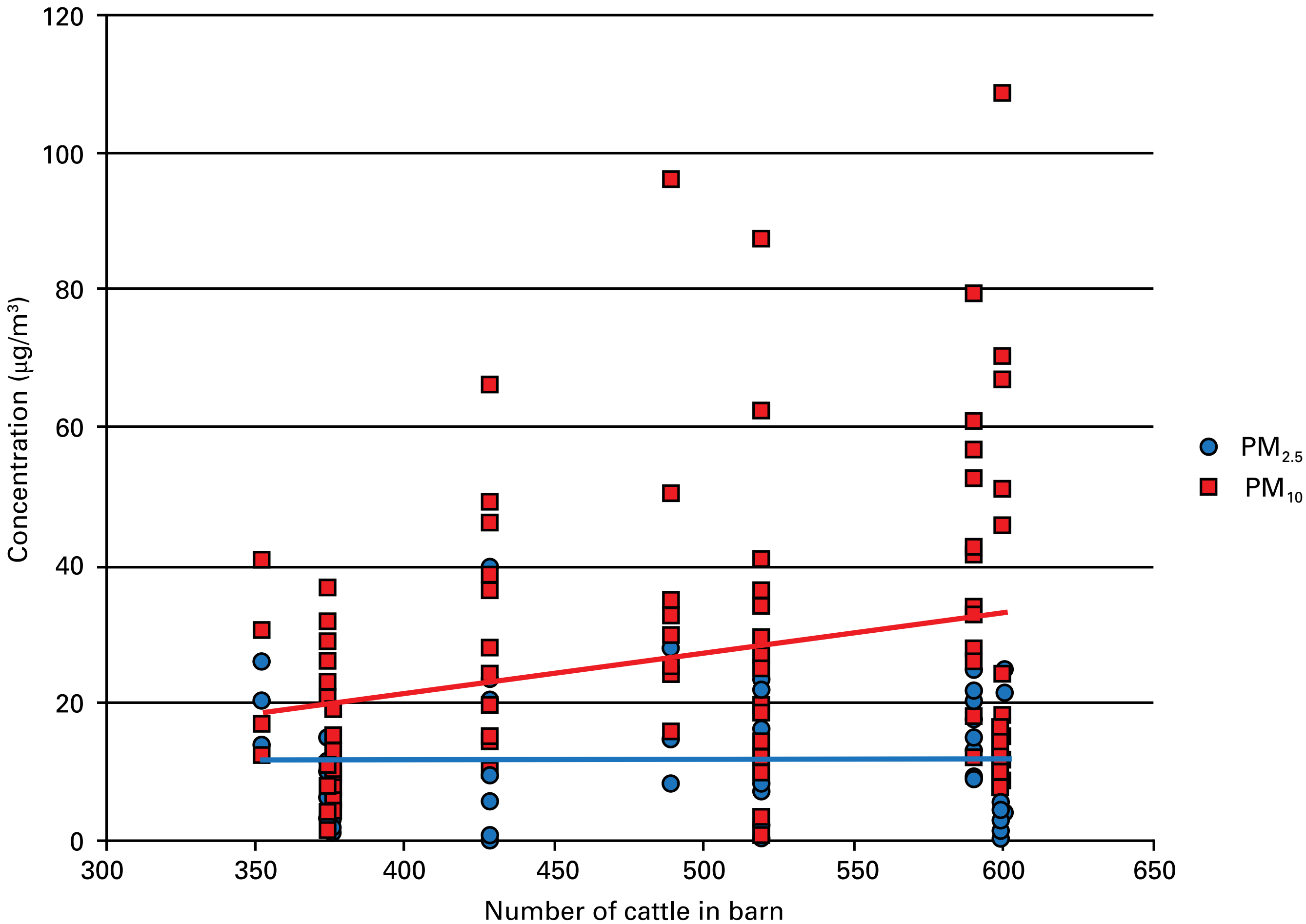

Figure 1. Effect of number of cattle in the barn on particulate matter concentration

PM_{10} concentration (µg/m^3) = -1.926 + 0.0584*Total number of cattle, R^2 = 0.0629
$PM_{2.5}$ concentration (µg/m^3) = 10.455 + 0.0027*Total number of cattle, R^2 = 0.0009

intermediate in odor activity and would adequately substitute for each other in a bedded barn. Dry cedar, green cedar, pine chips, and corn stover were also compared (Spiehs et al., 2013c). Calculated odor activity values were higher for green cedar bedding, followed by dry cedar, corn stover, and pine chip bedding, although differences in odor activity were not detected until Day 42.

Certain bedding materials may be better suited to a specific manure removal system. For instance, cedar bedding may be better in a Scrape system in which the bedding is removed more frequently and does not age for long periods of time (Spiehs et al., 2013c). However, corn stover and pine chips would be preferred in a Pack system as there was no significant increase in odorous compounds over time (Spiehs et al., 2013d).

VENTILATION/CURTAIN OPENING

Most mono-slope beef producers regulate ventilation in the barn by adjusting the amount of opening between the eave and the curtain. Usually, the curtain is wide open in the summer, whereas, in the winter, the opening is usually reduced. As the average ambient air speed increased, the airflow through the barns increased in a typically linear pattern. For example, with an 11 mph south wind, there were approximately 10 to 70 airchanges per hour for closed (1 to 2 foot) curtain conditions in the four barns, and 160 airchanges per hour with open (average 7 foot) curtain positions.

Decreased air movement through the barn increased the concentration of gases in the barn compared to higher airflow conditions and all other factors, such as temperature, being equal. But, reduced airflow through the barn resulted in decreased emission rates of ammonia, hydrogen sulfide, and methane.

MANURE HANDLING SYSTEM

This research project would suggest that both curtain opening and type of manure handling system may affect gas emission rates (Table 4). Emission is the product of the concentration and airflow through the barn. Ammonia and hydrogen sulfide emission rates for the Pack system were more variable than for the Scrape system. This increased variability may be attributed to age and condition of the pack. Increased pack depth is associated with a higher internal pack temperature that also may increase gas production. In the case of hydrogen sulfide, increasing pack depth and temperature can lead to anaerobic conditions, which promote hydrogen sulfide production.

Table 4. Range of daily average emission rates for ammonia and hydrogen sulfide with varying curtain openings and manure removal systems

	Manure Removal System	
Curtain Opening	**Scrape**	**Pack**
Open:		
Ammonia (g per head per d)	10-60	20-100
Hydrogen sulfide (mg per head per d)	<2	2-9
Closed:		
Ammonia (g per head per d)	<15	<30
Hydrogen sulfide (mg per head per d)	<.1	<1

Gas production and emission are also related to diet, animal characteristics, and animal activity. These factors were not monitored in this study and may account for some of variability in the emission rates in this study.

Open curtain

Partiallly closed curtain

Conclusions

In evaluating beef production systems and air quality, both controllable and uncontrollable (e.g., weather) factors should be considered. Fortunately, producers have the capability to manipulate a number of factors to improve overall air quality and animal comfort.

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Fenceline bunk

Animals in barn

Prepared by
Beth Doran, Kris Kohl, and Angie Rieck-Hinz – Iowa State University
Erin Cortus – South Dakota State University
Mindy Spiehs – U.S. Department of Agriculture, ARS, U.S. Meat Animal Research Center