Environmental Conditions in Beef Deep-Bedded Mono-Slope Facilities

A.S. Leaflet R2582

Mindy Spiehs, research animal scientist;
Bryan Woodbury, agricultural engineer;
Beth Doran, beef program specialist;
Roger Eigenberg, agricultural engineer;
Kris Kohl, agricultural engineer program specialist;
Vince Varel, microbiologist;
Elaine Berry, microbiologist;
James Wells, microbiologist,
USDA-ARS Meat Animal Research Center,
Iowa State University Extension

Summary and Implications

Ammonia (NH_3), temperature, moisture content, pH, pack depth, nutrient composition and concentration of odorous volatile organic compounds (VOC) were measured at 56 locations in each of four pens in two commercial beef deep-bedded mono-slope facilities (BDMF). Areas of high NH_3 concentration occurred randomly throughout the pens. Ammonia concentration increased as pack and ambient air temperature increased. Concentration of VOC was highest in transition areas between the bedded pack and the concrete floor. Depth, moisture content, and pH of the bedded pack did not influence concentration of NH_3 and VOC. Nutrient composition of the manure/bedding material in BDMF is similar to manure in open feedlots, except that in BDMF the volatile solids content is much higher. *E. coli* concentrations can occur at high levels in BDMF and vary with differences in ambient temperature. Priority should be given to NH_3 and *E. coli* mitigation during hot months. However, location-specific NH_3 mitigation will not be effective due to the random distribution of NH_3 in the pen. Frequent cleaning of the area surrounding the bedded pack should reduce VOC concentration.

Introduction

Interest in feeding beef animals in enclosed facilities in Iowa, South Dakota, Minnesota, and Nebraska has increased, primarily to reduce the environmental impact from feedlot run-off. Mono-slope barns are one popular style of deep-bedded confinement facilities. The mono-slope design facilitates natural ventilation and solar radiation. Producers cite ease of labor and manure management and improved performance compared to open feedlots.

However, no data is currently available regarding concentration of ammonia (NH_3) or other volatile organic compounds (VOC). There is little data about the nutrient composition of the bedding/manure material generated in BDMF. There also is no information regarding the prevalence, concentration, or survival of bacteria in the bedding/manure material from BDMF. Characterization of the factors impacting nuisance emissions is needed to develop recommendations on how to manage these facilities to reduce odor, gas emissions, and pathogens. Understanding the spatial variability of odorous compounds in the pen would allow producers to target management efforts at areas of the pen that contribute to offensive odors. Therefore, a study was initiated with the following objectives:

1. Determine spatial variability in NH_3 concentration from air samples collected at the pen surface of BDMF
2. Determining spatial variability of odorous compounds in the bedded pack material of BDMF
3. Quantify temperature, pH, moisture, and depth of bedding pack and relative humidity and temperature of the ambient air in BDMF during various seasons and determine the effect of these environmental factors on concentration of NH_3 and odorous compound in BDMF
4. Determine total nitrogen, phosphorus, potassium, and sulfur content of the bedded pack material from BDMF
5. Determine *E. coli* O157:H7 occurrence and generic *E. coli* concentrations in the bedded pack material from BDMF

Materials and Methods

Two commercial deep-bedded facilities in northwest Iowa were used for this project. Both barns are mono-slope barns with an east-west orientation and southern exposure. Management was site-specific, but the barns were typically cleaned and re-bedded one to two times per week. Chopped corn stalks were the primary bedding material. Pen density for cattle on feed 100 or more days ranged from 35 to 66 ft^2 per head, depending on the number of head in the pen and size of the animal.

Data were collected from two pens in each of two mono-slope barns every 5 to 7 weeks from March 2008 through October 2009. Cattle were removed from the pens immediately prior to data collection and were returned as soon as data collection was complete. In each pen, samples were collected from 56 locations on a 7 row × 8 column grid. The same 56 locations were sampled each time data was collected from the pen. Air samples were collected from the pen surface and analyzed for NH_3 concentration. Baseline NH_3 concentration of the pens was determined by collecting air samples from one pen in each barn at 0, 4-7, and 10 hours after the cattle were removed from the pen. Temperature and pH of the pen surface were measured approximately 6 inches below the surface. Depth of the bedded pack was determined by measuring elevation above the pen surface with a laser level. Ambient temperature and relative humidity (RH) were collected at locations inside and outside of each barn using temperature/RH data loggers. Samples of the bedding/manure mixture from the pen surface were collected and analyzed for dry matter (DM), volatile solids (VS), total nitrogen (TN), total phosphorus (TP), total potassium (TK) and total sulfur (TS), and *E. coli*. The following VOC were also measured: total volatile fatty acids (VFA), total straight-chain fatty acids (SCFA), total branch chain fatty acids (BCFA), and total aromatic compounds (phenol, indole, skatole, and p-cresol).

To determine spatial variability of NH_3, VFA, SCFA, BCFA, total aromatics, DM, and temperature, data were grouped according to bedded pack depth. Samples collected from areas of the pen with >6 in of bedding were designated "bedded pack" (P). Those collected from areas of the pen with 3-6 in and those from areas of the pen with <3 in of bedding were designated as "transition" (T) and "concrete" (C), respectively. Seasonal effects were determined by grouping data according to the average ambient temperature on the day of sampling. Cold, moderate, and hot seasons were defined as having an average ambient temperature at or below 32°F, between 32 and 69°F, and at or above 69°F, respectively.

Results and Discussion

Spatial Variability of Ammonia

There was no spatial pattern for NH_3 concentration in the pens (Table 1). Areas of high NH_3 concentration were found on the bedded pack, at the transition area between the bedded pack and concrete, and on the concrete pen surface. Within pen, areas of high NH_3 concentration varied from one sampling period to the next. When the time series collection was conducted, NH_3 concentration declined significantly between 0 and 4-7 hr after the cattle were removed from the pen, with no further significant decrease at 10 hr (data not shown). This indicated that locations in the pen with high NH_3 concentration were likely areas where cattle recently urinated instead of areas with consistently high NH_3 concentration. It appeared that a majority of the NH_3 volatilization occurred within the first four hours after excretion. Unfortunately, this means that areas of high NH_3 concentration occur randomly throughout the pen and location-specific mitigation (i.e., use of site-specific urease inhibitors or increased frequency of cleaning in a particular area of the pen) would not effectively lower NH_3 concentration in the barn.

Spatial variability of volatile organic compounds

Concentration of VFA, SCFA, BCFA, and aromatic compounds were lower on the P area compared to the T or C areas of the pen (Table 1). The samples collected from the P area contained feces and bedding material, while samples collected from the T and C area contained primarily feces. It is no surprise that the concentration of VOC is higher in the areas of the pen where feces are most concentrated. This emphasizes that frequent cleaning around the bedded pack may reduce the volatilization of VOC and improve air quality in the BDMF.

Seasonal differences in chemical and physical characteristics of the bedded pack

Ammonia concentration in air samples collected on the pen surface was lowest during the cold months and highest during the warm months, with intermediate values during months with moderate ambient temperature (Table 2). Temperature of the bedded pack was higher during the hot months compared to the moderate and cold months. The barn managers observed cattle lying on the concrete area surrounding the bedded pack instead of the bedded pack area during hot months. The T and C area of the pen were cooler and had higher moisture content, allowing for greater heat loss through evaporation and conduction (Table 1). Concentration of total VFA, SCFA, and total aromatic compounds was higher in bedding material collected from the pen surface during the cold and moderate months compared to the hot months (Table 2). This may be more a reflection of the bedding-to-feces ratio during the cold and moderate months than an actual temperature effect. Cattle tended to spend more time on the bedded pack with decreasing pack and ambient air temperatures which increased fecal and urine excretion on the bedded pack. The pH of the bedding/manure material was significantly higher during the months with moderate temperature compared to those with cold or hot temperature but did not appear to affect NH_3 or VOC concentration.

During each season, the ambient air temperature inside the barn was significantly higher than air temperature outside the barn (Table 3). Relative humidity was similar inside and outside of the barn during all three seasons. The calculated temperature humidity index (THI) inside the barn was significantly greater compared to outside the barn during the months when the weather was most extreme. A higher THI during the summer months seems to contradict producer reports that deep-bedded mono-slope facilities provide a more favorable environment for cattle during the hot months. However, we did not collect data to measure solar radiation, and THI fails to account for the effect of solar radiation, which can contribute substantially to the heat load in cattle. Shade provided by mono-slope facilities would likely decrease heat stress and improve performance during hot summer months.

Effect of chemical and physical characteristics of bedded pack on ammonia and VOC concentration

Ammonia concentration increased as the ambient air and bedded pack temperatures increased (Table 2). The bedded pack was warmer and drier during the hot months compared to cold and moderate months, which may have contributed to higher NH_3 concentrations from the bedded pack during the hot months. Moisture content influences NH_3 emissions.

In dry soil, the transport of NH_4^+ ions from the soil surface down to the deep soil horizon is restricted, hence, increased losses of nitrogen as NH_3 emissions from the soil occur. The drier bedded pack during the hot months may have contributed to higher concentration of NH_3 in the air samples from the pen surface of BDMF.

Ammonia volatilization is also influenced by pH. However, pH of the bedded packs in the two barns was poorly correlated to NH_3 concentration ($r^2 = 0.09$), likely due to small biological differences in pH levels within the pen. Depth of the bedded pack varied between seasons but also was poorly correlated to NH_3 concentration ($r^2 = 0.01$). Temperature, pH, moisture, and depth of the bedded pack were all poorly correlated to concentration of VFA, SCFA, BCFA, and total aromatics ($r^2 \leq 0.24$).

Temperature of the bedded pack influenced animal behavior. As previously stated, cattle were lying on the concrete area surrounding the bedded pack instead of the bedded pack area during the hot months. To improve animal comfort, Barn A changed bedding management in one pen during the second summer of the study. Instead of allowing the bedding pack to accumulate in the center of the pen during the summer months, all bedding and manure were removed from the pen once every three weeks. Fresh bedding material was added to cover the entire pen surface to a depth of approximately 12 in, and additional bedding was added once or twice weekly as needed. This created a shallow-bedded pack with a cooler temperature and higher moisture content, intended to improve animal comfort in the facility (Table 4). Ammonia concentration was not measured on these dates. However, based on the characteristics of the shallow-bedded pack, this management system may decrease NH_3 emissions compared to deep-bedded management, making it an effective management tool during hot months when NH_3 emissions are highest. A possible negative consequence of the shallow-bedded management is increased concentration of odorous compounds. The concentration of VFA, SCFA, BCFA, and total aromatic compounds was higher when shallow-bedded management was used, due to less bedding material in the pen and a higher manure:bedding ratio.

Nutrient Composition of Pen Surface Material

Total nitrogen, TP, TK, and TS in the manure/bedding from BDMF averaged 44.5, 14.1, 35.2, and 11.6 lb/ton, respectively. This is similar to reported values for manure from a beef earthen lot (45.2 lb/ton TN, 14.2 lb/ton TP, 36.8 lb/ton TK, and 11.8 lb/ton TS).The VS content of the manure from the BDMF is 80%. This is very high compared with other beef housing systems such as soil-surfaced open feedlots which contain 21% VS in manure and pens with a pond ash surface that contained 51%VS in manure. Thus, manure from BDMF may have additional value beyond use as a fertilizer, possibly for combustion.

Generic *E. coli* and *E. coli* O157:H7 prevalence

Among the 1046 bedding/manure samples examined for *E. coli* O157:H7 during the study, 418 (40.0%) were positive for this pathogen. Pen prevalence of *E. coli* O157:H7 ranged from 0 to 94.6%, and varied widely both within a pen across all sampling periods and within sampling period across all pens. The prevalence of *E. coli* 0157:H7 in the bedding/manure was higher during the hot months (Table2), which was likely due to the characteristic seasonality of prevalence of this pathogen in cattle. Fecal shedding of this pathogen typically increases during warmer months, and is often highest in summer and early fall. There were no consistent patterns of generic *E. coli* level with regard to location within the pens, with high and low concentrations of generic *E. coli* observed throughout the pens (data not shown). This may be due in part to the mixing action of animal movement. Generic *E. coli* concentrations were higher during the moderate and hot months compared to cold months. Similar to *E. coli* O157:H7, this is likely reflective of warmer temperatures that may promote growth or survival of *E. coli* in the bedding/manure material.

Conclusions

High spatial variability was observed for NH_3 concentration on the pen surface of BDMF. Areas with high NH_3 concentration were the result of recent urination of cattle. Ammonia concentration was higher when the pack and ambient air temperature increased and was consistently lower in the cold months compared to moderate and hot seasons. Therefore, priority should be given to NH_3 mitigation strategies in BDMF during the hot months. Volatile organic compounds were more concentrated in areas with little bedding and were poorly correlated to the temperature, moisture content, pH, and depth of the bedded pack. Frequent cleaning around the bedded pack should reduce the volatilization of VOC and may improve air quality in the BDMF. Nutrient composition of the bedding/manure is similar to manure from a beef earthen lot. The bedding/manure mixture generated in BDMF has 80% VS which is much higher than the VS content in manure from open lot feedlots. Both *E. coli* O157:H7 prevalence and generic *E. coli* concentrations can occur at high levels in the bedding/manure material of BDMF, and may vary with differences in ambient seasonal temperatures. Shallow-pack management may be a system that can lower barn NH_3 emissions during hot months. However, a possible negative consequence of shallow-bedded management is the increased concentration of odorous compounds in the pen surface manure.

Acknowledgments

The authors thank the barn managers for their willingness to participate in this study. Sincere appreciation is expressed to Todd Boman, John Holman, Shannon Kempers, and Maria Verburg for assistance with data collection, and to Al Kruger, Shannon Ostdiek, Dee Kucera, Bruce Jasch, and Sue Wise for laboratory analysis of samples. We gratefully acknowledge the grant from the Iowa Beef Center to partially fund this project.

Table 1. Concentration of ammonia and volatile organic compounds in various locations in beef deep-bedded mono-slope facilities. [1]

	Bedded pack[2]	Transition[3]	Concrete[4]
Ammonia, mmol/L	68.3 ± 2.8	63.9 ± 3.9	70.2 ± 3.4
VFA, mmol/g[5]	88.5 ± 5.8b	163.0 ± 8.2a	168.1 ± 6.3a
SCFA, mmol/g[6]	80.2 ± 5.6b	154.0 ± 8.0a	162.6 ± 6.2a
BCFA, mmol/g[7]	2.6 ± 0.2b	3.8 ± 0.3a	3.7 ± 0.2a
Aromatics, mmol/g[8]	2.2 ± 0.6b	12.8 ± 0.8a	11.7 ± 0.6a
Temperature, °F	78.3 ± 0.5a	66.2 ± 0.9b	63.0 ± 0.8c
Moisture, %	64.6 ± 0.3b	70.4 ± 0.5a	71.3 ± 0.4a

[1] N = 1257
[2] Bedded pack = area of pen having pack depth >6 inches.
[3] Transition = area in pen having pack depth 3-6 inches.
[4] Concrete = area of pen having pack depth <3 inches.
[5] VFA = total volatile fatty acids; Different letters within a row indicate a significant difference P < 0.01
[6] SCFA = total straight-chain fatty acids. Included acetate, butyrate, propionate, valerate, caproate, heptanoate, and caprylate;
[7] BCFA = total branch-chain fatty acids. Included isobutyrate, isovalerate, and isocaproate;
[8] Aromatics included *p*-cresol, phenol, 4-ethylphenol, skatole, and indole.
Different letters within a row indicate a significant difference P < 0.01

Table 2. Effect of season on pack characteristics in beef deep-bedded mono-slope facilities.

	Cold[1]	Moderate[2]	Hot[3]
Ammonia, mmol/L	14.8 ± 5.4c	57.6 ± 2.3b	99.5 ± 2.9a
Pack temperature, °F	59.7 ± 0.7c	69.5 ± 0.6b	84.4 ± 0.6a
Pack moisture, %	69.9 ± 0.5a	68.1 ± 0.4a	63.4 ± 0.5b
Pack depth, in	8.7 ± 0.4a	6.9 ± 0.3a	9.7 ± .3b
pH	7.5 ± 0.04a	8.0 ± 0.04b	7.5 ± 0.04a
Total VFA, mmol/g	156.1 ± 7.0b	154.5 ± 6.5b	91.5 ± 6.5a
Total SCFA, mmol/g	145.1 ± 6.7b	143.2 ± 6.3b	88.5 ± 6.3a
Total BCFA, mmol/g	3.5 ± 0.23	3.1 ± 0.21	3.0 ± 0.22
Total aromatics, mmol/g	9.7 ± 0.69b	9.63 ± 0.65b	4.21 ± 0.65a
E. coli O157:H7, % positive samples	30.0a	33.0a	50.2b
Average generic *E. coli*, $\log_{10}$ CFU/g	5.99 ± 0.05a	6.41 ± 0.04b	6.47 ± 0.02b

[1] Average ambient temperature for both barns on the day of collection was at or below 32°F.
[2] Average ambient temperature for both barns on the day of collection was between 32 and 69°F.
[3] Average ambient temperature for both barns on the day of collection was at or above 69°F.
Different letters within a row indicate a significant difference P < 0.01

Table 3. Differences in environmental conditions between the inside and outside of the beef deep-bedded mono-slope facilities during cold, moderate, and hot seasons[1]

	Temperature, °F		Relative Humidity, %		THI[2]	
	Inside	Outside	Inside	Outside	Inside	Outside
Cold	27.0x,A	20.3y,A	73.2	72.0	31.2x,A	24.9y,A
Moderate	53.1x,B	51.4y,B	68.3	68.5	53.8B	52.9B
Hot	75.0x,C	73.2y,C	70.3	66.8	72.1x,C	69.8y,C

[1] N = 4726. Outside temperature/relative humidity sensors were located at the barn site on an external support 9.8 feet above the ground. Inside sensors were positioned inside the mono-slope facility 10.8ft above the feedlot surface on the north side of an I-beam located in the middle of the pen. Cold = Average ambient temperature for both barns on the day of collection was at or below 32°F. Moderate = Average ambient temperature for both barns on the day of collection was between 32 and 69°F. Hot = Average ambient temperature for both barns on the day of collection was at or above 69°F.
[2] Temperature humidity index calculated as THI = td – (0.55 – 0.55RH)(td – 58) where td is the dry bulb temperature in °F and RH is relative humidity expressed as a decimal.
Different lowercase letters within a row indicate a significant difference between inside and outside readings within a season (P < 0.01). Different uppercase letters within a column indicate a significant seasonal difference for variable (P < 0.01).

Table 4. Effect of bedding management on pack characteristics of beef deep-bedded mono-slope facilities.

	Deep-bedded management[1]	Shallow-bedded management[2]
Pack moisture, %	63.1 ± 0.6 a	67.2 ± 0.6 b
Pack temperature, °F	70.2 ± 1.1 a	65.2 ± 0.9 b
Total VFA, mmol L^{-1}	73.8 ± 10.4 a	142.0 ± 10.5 b
Straight-chain VFA, mmol/L	71.7 ± 10.1 a	138.2 ± 10.1 b
Branch-chain VFA, mmol/L	2.1 ± 0.4 a	3.8 ± 0.4 b
Aromatics, mmol/L	2.6 ± 0.4 a	4.4 ± 0.4 b
Volatile solids, %	83.8 ± 0.2	87.1 ± 0.2

[1] Deep-bedded management: A bedded pack is allowed to accumulate in the center of the pen while cattle were in barn. Area around the pack was scraped and removed and fresh bedding added to the pack once weekly. Data are from one pen in Barn A during April, June, and Aug 2009.
2 Shallow-bedded management: All bedding and manure are completely removed every three weeks. Fresh bedding is added as needed but no bedded pack is allowed to accumulate. Data are from one pen in Barn A during April, June, and Aug 2009.
Different letters within a row indicate a significant difference $P \leq 0.01$