Alternative Bedding Materials for Compost Bedded Pack Barns in Minnesota: A Descriptive Study

E. M. Shane, M. I. Endres, K. A. Janni

Abstract. *Bedding availability for compost bedded pack barns is a concern for dairy producers who use this type of daily stirred bedded pack housing system. The material most commonly used in these barns is sawdust. The objective of this study was to describe management practices of dairy operations utilizing alternative bedding materials for partial or total replacement of sawdust in their compost barns. This study was conducted on six Minnesota dairy farms having compost bedded packs. Bedding materials used on these farms included: sawdust, wood chips, flax straw, wheat straw, oat hulls, strawdust, and soybean straw. Each farm was visited four times, once each season between January 2008 and November 2008. Replicated samples of the bedded pack material were collected during winter and summer. Samples were analyzed for dry matter, carbon, nitrogen, C:N ratios, ammonium, nitrate, pH, and bacterial counts. Temperatures of each pack were measured seasonally at various depths. Cows were scored for hygiene (1=clean, 5=dirty), body condition (1=thin, 5=obese), and locomotion (1=normal, 5=severely lame), and hock lesions were observed. Aerial ammonia and hydrogen sulfide concentrations, air velocity, and light intensity were measured each season. Overall average aerial ammonia was 3.92 ppm and hydrogen sulfide was 22.8 ppb across all farms and season. Average light intensity was 3,250 lux and air velocity was 0.81 m/s. Bedding pack material averaged 15.8% for total C, 0.93% for total N, 17.8 for C:N ratio, 37.3% for dry matter, 8.83 for pH, 4.25 mg/kg for nitrate, 955 mg/kg for ammonium, 15 g/kg for total potassium, 2.8 g/kg for total phosphorus, 8.5 dS/m for EC, 31.7°C for pack temperature, 7.6°C for outside temperature, and 9.42 million cfu/mL for total bacterial counts in the bedding. Based on these results and our observations, it appears that any of the bedding materials evaluated in this study used to substitute or partially substitute for sawdust can work well in compost dairy barns if the pack is consistently well managed by tilling twice daily, providing proper ventilation to keep surface of pack dry, and adding new material when it is visually adhering to the cows.*

Keywords. *Compost barn, Bedded pack, Dairy cow, Housing.*

Compost dairy barns are an alternative loose housing system for dairy cows. The barns have an open bedded pack resting area separated from the feed alley by a 1.2-m high concrete wall. Fresh bedding is added to the resting area when bedding material starts to adhere to the cows. The most commonly used bedding material is dry sawdust. Unlike conventional bedded packs, compost packs are tilled or stirred twice daily to incorporate the manure, provide a fresh, dry surface, and aerate the pack to encourage aerobic microbial activity in the pack (Janni et al., 2007). Compost dairy barns are known for good cow comfort, health, and longevity, and ease of completing daily chores (Barberg et al., 2007a,b). These barns are being used in many states in the United States (especially in the Midwest and Northeast) and in other countries (such as Japan, China, Germany, and Holland).

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The authors are **Erika M. Shane,** Graduate Student, **Marcia I. Endres, ASABE Member,** Associate Professor, Department of Animal Science, University of Minnesota, St. Paul, Minnesota; and **Kevin A. Janni, ASABE Member Engineer,** Professor, Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, Minnesota. **Corresponding author:** Marcia I. Endres, Department of Animal Science, University of Minnesota, 1364 Eckles Ave., St. Paul, MN 55108; phone: 612-624-5391; fax: 612-625-1283; e-mail: miendres@umn.edu.

Barberg et al. (2007a,b) conducted a study during the summer season to describe compost dairy barns using sawdust bedding. The main concern expressed by producers during that study was the cost and lack of availability of sawdust. Therefore research was needed on alternative bedding materials that could work in these systems. The objective of this study was to describe management practices of dairy operations utilizing alternative bedding materials in their compost barns.

Material and Methods

Six Minnesota dairy farms with compost bedded packs were enrolled in the study. Farms were selected based on the alternative bedding materials being used in their compost barns. Bedding materials used on these farms included: sawdust, wood chips, flax straw, wheat straw, oat hulls, strawdust, and soybean straw. The weight of each bedding material used during the study was recorded by each producer as delivered to the dairy farm. Each farm was visited four times, once each season between January 2008 and November 2008. Building, fan, lighting, bedding and management information for each farm was collected between October 2007 and November 2008.

Bedding Chemical Analysis

Each compost barn pack was subdivided into four equal areas from which 0.5-L bedding samples were collected

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during winter and summer. Bedding samples were taken at two depths (15 and 30.5 cm), if the pack depth was sufficient, using a hand-operated soil auger (Edelman auger, Eijkelkamp Agrisearch Equipment, Giesbeek, The Netherlands). Samples were kept cold after collection and later frozen at -40°C until drying and further analysis. Sub-samples were ground as-is in a food processer before analysis for ammonium (NH_4-N), nitrate (NO_3-N), pH, total carbon (C), and total nitrogen (N). The remaining sample was dried in a 60°C oven for 48 h and ground in a Wiley Mill with a 1-mm screen prior to analysis for total phosphorus (P), total potassium (K), and electrical conductance (EC) (soluble salts). Sub-samples were further dried in a 100°C oven for 24 h to obtain absolute dry matter. Samples were not allowed to cool before weighing. Chemical analysis of the bedding material samples was conducted by the University of Minnesota Soil Testing and Analytical Lab. Ammonium and NO_3-N concentrations were determined by shaking 3 g of moist sample with 30 mL of 2 M KCl for 30 min. The extract was analyzed colorimetrically on an Alpkem RFA 300 at 660 nm (Sparks, 1996). Total carbon was determined by dry combustion at 1370°C and subsequent measurement of CO_2 evolution by an infrared detector [LECO CR-12 carbon furnace] (Sparks, 1996). Total N was determined by the DUMAS combustion method using a LECO 528 analyzer (Sparks et al., 1996). The pH was determined on a 1:1 sample/water mixture measured using a Beckman pH meter with glass and calomel reference electrode calibrated to buffers pH 4 and 7 (Sparks et al., 1996). EC was determined by making a water saturated sample paste with 100-cc volume of bedding sample. After intermittent stirring and equilibration for 2 h, the free water was extracted by filtration. The filter/supernatant was measured for electrical conductance and expressed as dS/m (Sparks et al., 1996). Total P and K samples (500-mg dry sample) were weighed into a covered 20-mL quartz crucible, heated for 10 h at 485°C, and then cooled to room temperature. Five mL of 20% HCl was added to dissolve the ash. After 30 min, 5-mL of deionized water was added, the sample was allowed to stand for 2 h to let the undissolved ash settle, and the supernatant was transferred into a 15-mL test tube to run through an Inductively Coupled Plasma Atomic Emission Spectrometer [ARL (Fisons) Model 3560 ICP-AES]; (Fassel and Kniseley, 1974). Results are expressed on an 'as-is' basis with the exception of total P, total K, and EC which were expressed on a DM basis.

Bedding Bacterial Analysis

Surface samples were collected for bacterial culture in the four areas described previously. A composite of five bedding surface samples was collected within each of the four areas. The bedding samples were immediately cooled upon collection and later frozen at -40°C until further analysis by the University of Minnesota Laboratory for Udder Health. The samples were thawed in a refrigerator. Fifty cubic centimeters (cc) of bedding material was measured using a sterile container and placed into a Whirl-Pak® bag (Nasco, Fort Atkinson, Wis.). Two-hundred fifty cc of sterile distilled water was added to the bedding material which was mixed and allowed to stand for 10 min. The sample was mixed again, a liquid sample was removed by pipette and serial 10-fold dilutions were made in sterile Brain Heart Infusion broth. Sample dilutions were plated (200 µL) on colistin naladixic acid (CNA) agar (BBL, Sparks, Md.), MacConkey agar (BBL, Sparks, Md.), and thallium sulfate-crystal violet-B toxin blood (TKT) agar medium. Colony counts were determined for each sample after 24 h of incubation at 37°C. Bacterial groups were identified as coliforms (lactose-positive colonies on MacConkey's agar, which include *Klebsiella* by visual identification), streptococcus species (growth on TKT agar), Bacillus species (growth on CNA agar and gram-positive) and coagulase negative staphylococci (growth on the CNA agar and catalase activity). Bacteria counts are expressed as colony forming units (cfu)/mL of bedding sample.

Bulk Tank Bacterial Analysis

Bulk tank milk samples were collected from five consecutive bulk tank pickup days the week of our visit (samples were taken at the time milk was collected from the dairy by the processor after thorough mixing of the bulk tank milk) and frozen daily before being taken to the Laboratory for Udder Health, University of Minnesota and used for bacterial culture. Samples were collected during the winter and summer. For analysis, samples were thawed in a refrigerator. Once thawed, samples were thoroughly mixed, and 2 mL were removed from each sample and pooled into a sterile tube. After mixing, serial 10-fold dilutions were made in sterile brain heart infusion broth. Two hundred microliters from each dilution were spread over the surface of separate MacConkey agar, TKT agar, and Factor agar plates. After 24 h of incubation at 37°C, the plates having 30 to 300 colonies were chosen for enumeration of bacteria. Those colonies that appeared to be *Staphylococcus aureus* were presumptively identified by catalase activity, tube coagulase test, and biochemical reactions using the API-STAPH (BioMerieux, Hazelwood, Mo.). Bacterial counts are recorded as number of bacteria per mL of bulk tank milk.

Environmental Measurements

Aerial ammonia and hydrogen sulfide concentrations, air velocity, and light intensity were measured in the barns each season. Five measurements were taken in the compost pack area and 5 in the feed alley twice during the day. Ammonia was measured using a Dräger Pac III meter (Dräger Safety Inc., Pittsburg, Pa.). Hydrogen sulfide was measured using a Jerome 631-X meter (Jerome Hydrogen Sulfide Analyzer; Arizona Instrument LLC, Tempe, Ariz.). Air velocity was measured using an anemometer (TSI VELOCICHEC® Air Velocity meter, Model 8330; TSI, Inc., Shoreview, Minn.). Light intensity was measured with a digital light meter at 140 cm from the floor (model TES1337; TES Electrical Electronic Corp.; Taiwan, ROC). Light, emissions, and air velocity results were included to provide a more complete description of the environment in these barns.

Cow Characteristics

Body condition, hygiene, and locomotion scores were recorded once seasonally. Cows were scored for body condition on a scale of 1 to 5, where 1 = thin and 5 = obese (Ferguson et al., 1994). Cow hygiene was measured using a scale of 1 to 5, where 1 = clean and 5 = very dirty (Reneau et al., 2005). Lameness was observed and scored using the five-point locomotion scoring system of Flower and Weary

(2006), where 1 = normal locomotion, 2 = imperfect locomotion, 3 = lame, 4 = moderately to severely lame, and 5 = severely lame. A locomotion score of 3 indicates lame cases and score of ≥4 indicates severely lame cases. Cows were also scored for hock lesions. Hock lesions were identified as no lesion, mild lesion (hair loss), and severe lesion (swollen hocks with or without hair loss). Cow herd records were obtained from Dairy Herd Improvement Association (DHIA) from January 2008 to November 2008. Kilograms of milk, milk fat %, milk protein %, fat corrected milk (FCM), days in milk (DIM), and somatic cell counts (SCC) were recorded.

Temperature Measurements

Pack temperature was measured at either four or five locations across each pack at two depths (15 and 30 cm), if sufficient pack depth was available, using an Omega compost thermometer (91-cm length, accuracy of ±1°C; Omega Engineering Inc., Stamford, Conn.).

Outside temperature was obtained from a weather station closest to the farm (Minnesota Climatology Working Group, http://climate.umn.edu/). Daily weather station minimum and maximum air temperatures were used to indicate the temperature range the barns were experiencing.

Statistical Analysis

Descriptive statistical analysis (mean, st. dev., range, quartiles) for each measurement was performed using Proc Means of SAS (SAS Inst. Inc., Cary, N.C.).

Results and Discussion

Farm and Barn Characteristics

Barn Facilities

Barn and compost pack characteristics, number of cows, space per cow, number of waterers, sidewall height, and feed alley width are listed in table 1. All of the barns were naturally ventilated. Cooling fan number, size, and location are listed in table 2 along with number of lamps, location, and type.

Barn A was built in 2006 and cost $225,000. Sidewall curtains were open during summer, closed during winter. Barn A had 126 headlocks along a covered drive-by feed manger in the barn. The covered driveway on the south side of the barn was 4.3 m wide.

Barn B was built in 2005 and cost approximately $220,000. Curtains stayed open all summer and were closed during the winter. There were no headlocks. A drive-by feed manger was located on the south side of the barn under a 1.3-m eave overhang.

Barn C was built in 2004 and cost approximately $140,000. There were 76 headlocks. A covered drive-by feed manger was located in the barn on the south side. The covered driveway was 4.9 m wide.

Barn D was built in winter 2005-06 and cost $82,000. There were 83 headlocks. Top and bottom curtains were open all summer and the bottom curtain was closed during the winter. The barn had a drive-by feed manger that was located on the outside of the barn on the south side under a 1.3-m eave overhang.

Barn E was built in the summer of 2006 and cost approximately $100,000. The covered drive-by feed manger was located in the barn on the south side along the whole length of the barn. There were no headlocks. The covered driveway was 4.3 m wide.

Table 1. Barn characteristics of six compost dairy barns in Minnesota.

Barn[a]	Barn Dimensions (m × m)	Sidewall Height (m)	Feed Alley Width (m)	Pack Dimensions (m × m)	No. of Cows	Pack Area (m^2/cow)	No. of Waterers
A	22 × 78	4.9	4.3	14 × 78	190	5.8	2
B	15 × 61	4.9	4.3	11 × 61	130	5.2	4
C	23 × 46	4.9	3.7	15 × 46	100	6.9	4
D	23 × 61	4.9	4.4	18 × 49	110	8.0	4
E	19 × 50	5.0	3.4	11 × 50	75	7.3	3
F	30 × 95	4.9	3.4	8 × 46	50	7.4	3

[a] Farm F has a total of 200 cows with 50 per pen. Measurements are for each individual pen, which are similar to each other.

Table 2. Description of barn fans and lights in six compost dairy barns in Minnesota.

Barn	Fan Description	Lighting Description
A	Four 7.3-m diameter fans horizontally mounted over the pack; five 1.4-m diameter fans (4.3 m wide) over feed alley	Twenty-four fluorescent lights over pack; Twelve fluorescent lights over feed alley
B	Three 7.3-m diameter fans horizontally mounted over the pack	Seven low bay halogen lights over pack; Eight low bay halogen lights over feed alley
C	Ten 1.3-m diameter fans over the feed alley; additional fans added over pack in the summer	Twelve lights located over pack; Six lights located over feed alley
D	Eleven 1.4-m diameter fans angled over the pack	Twenty-five fluorescent lights over pack; Nine fluorescent lights down feed manger
E	Seven ceiling fans hanging from the eves over the pack	Four fluorescent lights over feed alley
F	Six 1.2-m diameter fans distributed over pack; Three 1.2-m diameter fans located over feed alley	Two halogen lights over pack; Six halogen lights down feed manger

Barn F was a drive through barn with two pens on each side. The barn was built in 2003 and cost $350,000. Each pen had 48 headlocks plus 9.8 m of post-and-rail feed manger. The driveway down the center of the barn was 5.5 m wide.

All the farms agreed that the reason the compost barn was built was to improve cow comfort. The reason for using alternative bedding materials was reduced availability and the increasing price of sawdust.

The farms participating in the study represent the typical herd sizes housed in compost dairy barns, ranging from 50 to 200 cows. Four out of six study farms provided less than the recommended resting area of 7.4 m^2/cow (Janni et al., 2007)

Bedding Material

Farm A used a number of different bedding materials in their barn over the 1-yr study period. These included: sawdust, wood chips, flax straw, and wheat straw. For a portion of the study, this barn was not managed as a compost dairy barn. During the winter and fall visits, the pack was being treated as a conventional bedded pack because of the cost of sawdust and difficulties keeping the pack warm and dry. Straw ground to 2.5 cm was added once a day and the conventional pack was not tilled or stirred. After removal of most of this material late winter, sawdust (mixed with other material as available) was added. During the spring and summer the barn was managed like a compost barn and tilled twice a day.

At the beginning of the study, farm B was using sawdust (90%) and oat hulls (10%) to bed the pack. Oat hulls were added a few times throughout the 1-yr monitoring period. Approximately 6.12 metric tons of bedding material (primarily sawdust) was added weekly. To start a new pack in the fall, after most of the old pack had been removed and land applied, this farm took bedding from the area next to the concrete wall and mixed it with 6.12 metric tons of new sawdust.

Farm C used a material called "strawdust" to bed the pack. This was a by-product of wheat and was a very fine material. Between 4.54 and 12.7 metric tons were added each week. This was the only farm in the study that did not use some sawdust for bedding.

For the winter time, farm D had a protocol to bed three times each week in the evening using sawdust alone or a mix of sawdust and soybean straw. The soybean straw was harvested with a forage chopper at the smallest length of cut. This farm used a chisel plow to till the pack twice a week during the winter besides tilling twice daily with a cultivator. Between October and December 2007, 5.44 to 6.35 metric tons of sawdust was added each week. Between December and April 2008, 265 metric tons (14.5 metric tons each week) of sawdust and 62.8 metric tons (3.48 metric tons each week) of soybean straw were added to the pack. Between April and May 2008, 5.44 to 6.35 metric tons of sawdust was added each week. Between May and September 2008, no bedding was added. A total of 417 metric tons of material was used over the 1-yr study period.

In fall 2007, farm E started the pack using chopped wheat straw adding approximately 1.8 metric tons once a week. Between September 2007 and January 2008, a total of 9.1 metric tons of chopped soybean straw, 5.5 metric tons of chopped wheat straw, 10.9 metric tons of sawdust, and 9.1 metric tons of wheat strawdust were added. Any one of these materials was added once each week. Between February and April 2008, 0.45 metric tons was added every 7 days, and between April and August 2008, 0.45 metric tons of sawdust was added every 4 days. In the first part of August, 0.45 metric tons of wheat strawdust was added every 4 days. The protocol for starting a new pack after cleanout was to add either 0.60 metric tons of sawdust or wheat strawdust, and start to till the pack once 30 cm of bedding was added. When new bedding was added each week, they did not till the pack until the next day.

For farm F, five times during the winter, soybean stubble (36 bales) was used instead of sawdust to bed the four pens. They used their own soybean straw bales (0.39 metric tons). Sawdust was used the rest of the year when it was available. Each time a semi-truck load of sawdust (approximately 16.8 metric tons) was delivered, the load was distributed over the four pens. The protocol to start a new pack was to take the used material next to the concrete wall and add 15.2 cm of clean material with it.

Bedding Management

All farms tilled or stirred the compost pack twice daily during milking time using a cultivator, a rotary tiller, or a chisel plow (deeper tillage). Typically, cleanout of the barn was performed twice yearly, spring and fall. Five farms followed this scheme. Farm A cleaned the pack out more than twice to keep the bedding fresh and dry because this barn was managed more like a conventional bedded pack for a portion of the year.

Milking Procedures

Milking procedure varied from farm to farm. Milking protocol should include good pre-dip coverage to eliminate bacteria, forestripping, proper drying of teats before the milking unit is placed, and good post-dip coverage to prevent bacteria from entering the teat canal after milking (http://www.uwex.edu/milkquality/PDF/Vol_3_pdf/Pg_3-13-14_standard_ops.pdf).

The farm A milking procedure was to dust teats with a dry cloth, clean teats using a moist wipe, forestrip teats, dry teats, and then apply the milking unit. This farm had a double four step-up parlor.

The farm B milking procedure was to dip teats with pre-dip solution, dry teats, and apply the milking unit to each cow. No forestripping was performed. This farm had a double four step-up parlor.

The farm C milking procedure was to dip four cows with 1% iodine solution, forestrip four cows, dry four cows, and then put milking units on four cows. This farm had a double six swing parabone parlor.

The farm D milking procedure was to dip four cows, strip and dry four cows, and then put milking machine on four cows. This farm had a double eight swing parallel parlor.

The farm E milking procedure was to dip teats with glycerin solution, wipe with wet towel, dry, and apply milking machine; only forestrip teats on problem cows. In the fall the pre-dip solution was changed from soap and water to a glycerin solution. This farm used a tiestall for milking.

The farm F milking procedure was to pre-dip teats with 1% iodine solution, forestrip, dry, and apply milking unit. This farm had a double eight step-up parlor.

Pack Temperature

Table 3 shows the average pack temperatures at two depths and outside temperatures for each season and farm. Results at two depths were combined because temperatures were similar in all barns for the two depths. Missing values mean that the pack depth was insufficient to measure. Pack temperature was measured at only 15 cm if the pack was less than 30 cm deep. All compost packs were warmer than the outside temperature in each season. This indicates that the packs were heating and microbial activity was occurring. Barberg et al. (2007a) reported a pack temperature at two depths of 42.5°C during the summer season. In the current study, we measured pack temperatures that ranged from 31.8°C to 48.1°C in the summer and 13.8°C to 40.6°C in the winter. Farms C and D had the highest pack temperatures during all seasons except for fall when farm E had the highest pack temperature. The elevated pack temperatures observed suggest that all of bedding materials were able to support microbial activity and produce heat when stirred twice a day.

Table 3. Average pack and outside temperatures in six compost dairy barns in Minnesota.

Season Barn	Temperature (°C) Compost Pack	Minimum Outside	Maximum Outside
Winter			
A	n/a	-14.3	-3.5
B	7.7	-14.0	-2.3
C	28.1	-13.1	-3.4
D	40.6	-15.0	-4.0
E	13.8	-16.3	-5.1
F	17.6	-14.9	-4.3
Spring			
A	n/a	4.3	15.8
B	n/a	3.6	15.6
C	39.4	5.2	16.5
D	38.3	4.3	15.8
E	20.8	4.6	15.8
F	25.5	3.8	16.0
Summer			
A	33.3	14.8	26.8
B	35.2	13.5	26.8
C	48.1	14.1	26.6
D	40.1	14.8	26.8
E	32.8	14.1	27.3
F	31.8	13.1	26.4
Fall			
A	n/a	9.6	20.2
B	27.0	8.4	20.6
C	40.9	5.3	18.2
D	31.0	6.3	16.8
E	42.2	8.8	22.7
F	32.8	6.6	21.6
Average[a]	31.7	13.3	1.9

[a] Average across seasons and barns.

Chemical Analysis

Table 4 reports the average total C, total N, C:N Ratio, NH_4-N, NO_3-N, pH, total K, total P, and DM. Each value is an average of four or eight samples collected from four areas in each pack at 15- or 30-cm depth. Total C ranged from 12.7% to 20.1% during winter and 15.3% to 17.4% during summer. Farms were similar for each season. Total N ranged from 0.61% to 0.89% during winter and 0.89% to 1.23% during summer. Barberg et al. (2007a) reported an average total N of 2.54% with a range of 0.57% to 4.22% (dry matter basis). Russelle et al. (2009) reported average N of 1.12% in eight compost barns in Minnesota. C:N ratio ranged from 16 to 26 during winter and 13 to 18 during summer. Barberg et al. (2007) reported an average of 19.5 across all barns sampled. Russelle et al. (2009) reported a range of 11.2 to 20.9. Farm A had the highest C:N ratio for both seasons. We observed a range of 384 to 1,460 mg/kg for NH_4-N during winter and a range of 568 to 1,270 mg/kg during summer. For NO_3-N, we observed a range of 1.33 to 1.68 mg/kg for winter and a range of 1.40 to 21.4 mg/kg for summer. The pH ranged from 8.5 to 8.9 during winter and 8.7 to 9.1 during summer. Barberg et al. (2007) reported an average pH of 8.4 to 8.6 during summer.

Total K ranged from 7.8 to 19.2 g/kg during winter and 14.2 to 22.7 g/kg during summer. Barberg et al. (2007) reported a range of 2.6 to 29.6 g/kg during summer. For total P, they reported a range of 0.38 to 6.7 g/kg during summer whereas we found a range of 2.8 to 4.3 g/kg for our summer measurements. For our winter measurements, we observed a range of 1.5 to 2.6 g/kg. EC ranged from 4.3 to 12.5 dS/m during winter and 6.5 to 13.3 dS/m during summer. Dry matter ranged from 29.6% to 41.9% during winter and 36.0% to 45.8% during summer. Barberg et al. (2007) reported 54.4% dry matter during summer, whereas Russelle et al. (2009) reported DM of 39% for the surface layer and 36% for the more compact layer. Overall the chemical analysis from the six barns in the study using alternative bedding was similar to those reported previously by Barberg et al. (2007) and Russelle et al. (2009).

Bacterial Analysis

Table 5 shows the pack bacterial counts for each farm during the winter and summer visits. The environmental *Streptococcus* counts were higher in the winter than the summer. Also, *Bacillus* sp. were higher in the summer for all farms. Magnusson et al. (2007) found a positive correlation between *Bacillus* counts in used bedding material and raw milk. *Bacillus* can survive pasteurization and shorten milk shelf life. Only three farms had a spike of *Staphylococcus* species in the summer compared to no farms in the winter. Table 6 shows the bacterial counts of the bulk tank milk for each farm for winter and summer. *Streptococcus agalactiae* was not present in either season in any farm. *Staphylococcus aureus* was higher in winter than summer. Coliforms increased in the summer compared to winter. It has been suggested that excellent milking preparation procedures are essential in maintaining low SCC with such high bacterial counts in the bedding material (Barberg et al., 2007b).

Environmental Characteristics

Aerial ammonia and hydrogen sulfide concentrations, air velocity, and light intensity are shown in table 7 by season

Table 4. Bedding chemical characteristics in six compost dairy barns in Minnesota.

Season Farm	Item Total C (%)	Total N (%)	C:N Ratio	NH_4-N (mg/kg)	NO_3-N (mg/kg)	pH	Total K (g/kg DM)	Total P (g/kg DM)	DM (%)	EC (dS/m)
Winter										
A	17.1	0.66	26.0	742	1.33	8.78	12.4	1.8	32.3	7.2
B	14.0	0.61	23.2	593	1.36	8.94	10.7	2.6	29.6	5.4
C	12.7	0.80	16.0	1,459	1.68	8.69	19.2	2.2	34.0	12.5
D	20.1	0.89	23.6	384	1.41	8.94	7.8	1.5	41.9	4.4
E	15.3	0.85	18.0	955	1.40	8.53	13.5	2.5	32.9	7.8
F	13.7	0.78	17.6	1,128	1.35	8.56	8.6	2.5	33.1	5.7
Summer										
A	16.3	0.89	18.2	689	21.4	8.90	22.4	3.0	36.0	11.9
B	16.2	0.91	17.9	887	6.41	9.14	15.5	3.3	36.1	6.5
C	15.3	1.03	14.7	1,272	2.20	8.73	22.7	2.8	42.6	13.3
D	17.4	0.98	17.8	776	13.1	8.88	17.0	3.0	40.9	9.9
E	16.2	1.11	14.7	568	1.40	9.05	22.4	4.3	45.8	12.1
F	16.0	1.23	13.1	1,267	3.28	8.84	14.2	3.5	39.1	8.4
Average[a]	15.8	0.93	17.8	955	4.25	8.83	15.0	2.8	37.3	8.5

[a] Average across seasons and farms.

and farm and at the feed bunk and compost pack areas separately. Overall ammonia was 3.9 ppm, hydrogen sulfide was 23 ppb, light intensity was 3,250 lux, and air velocity was 0.81 m/s.

According to the National Institute for Occupational Safety and Health (NIOSH), during a 40-h work week, with up to 10-h work days, ammonia exposure should not exceed 25 ppm. Occupational Safety and Health Administration (OSHA) recommendations are a bit higher with an exposure limit of 50 ppm for up to an 8-h work day of a 40-h work week (Mitloehner and Calvo, 2008). None of the farms had concentrations near 25 ppm that would be expected to interfere with the workers. NIOSH recommends during a 10-h work day in a 40-h work week that hydrogen sulfide levels should not exceed 10 ppm and OSHA has a maximum peak of 50 ppm for 10 min (Mitloehner and Calvo, 2008). None of the farms had hydrogen sulfide concentrations that would be expected to interfere with the workers.

Peters et al. (2000) recommends 215 lux (20 foot candles) of lighting over the feed bunk. All barns exceeded this value for all seasons except barn F, which was lower in the winter (152 lux) and spring (125 lux).

Cow Characteristics

Body condition (BCS) and hygiene scores (HS), are shown in table 8. BCS were 3.03 with a range of 2.81 to 3.26. Barberg et al. (2007b) reported a BCS of 3.04 with a range of 2.88 to 3.17, which is similar to our findings. They also reported an average HS of 2.7 with a range of 2.3 to 2.9, whereas we observed a HS of 3.1 with a range of 2.2 to 3.8 across seasons and farms.

Table 5. Bacterial analysis of bedding samples in six compost dairy barns in Minnesota.

Season Farm	Bacteria (cfu/mL) Klebsiella (% of Coliforms)	Coliforms (‘000’s)	Environ. Strep (‘000,000’s)	Staph species (‘000’s)	Bacillus (‘000’s)
Winter					
A	0.75	102	10.46	0.0	0.0
B	12.8	1.9	9.05	0.0	25
C	0.0	0.0	0.33	0.0	249.7
D	1.25	123	18.90	0.0	0.0
E	1.25	5.6	20.15	0.0	43.8
F	2.13	16.5	7.99	0.0	0.8
Summer					
A	0.0	34.5	1.21	0.0	162.5
B	0.0	73.5	6.26	0.03	1,200
C	0.75	6.2	0.11	0.0	2,093
D	0.25	11.4	0.37	0.0	253.8
E	1.25	533.7	4.77	1,850	2,768
F	5.75	537.5	4.81	41.8	903.1
Average[a]	2.43	142.8	6.94	138.1	614.6

[a] Average across seasons and farms.

Table 6. Bacterial analysis of milk bulk tank samples in six compost dairy barns in Minnesota.

Season Farm	Bacteria (cfu/mL) Coliforms	Environ. Strep	Staph aureus	Staph Species
Winter				
A	15	132	35	108
B	15	585	0.0	30
C	20	98	28	50
D	305	2,550	0.0	35
E	35	48,400	55	0.0
F	1,128	600	0.0	50
Summer				
A	Too numerous[a]	Too numerous	0.0	Too numerous
B	50	720	5	20
C	14,000	55	0.0	40
D	383	918	0.0	283
E	Too numerous	Too numerous	0.0	Too numerous
F	9,600	1,250	5	0.0

[a] Greater than 50,000,000 cfu/mL.

Table 9 shows the prevalence of lameness and hock lesions. We observed a prevalence of lameness of 7.1% lame, 2.0% severely lame during fall; 9.7% lame, 2.4% severely lame during spring; 10.2% lame, 2.0% severely lame during summer; and 9.2% lame, 3.8% severely lame during winter. Overall, 9.1% of cows were lame and 2.5% were severely lame. Barberg et al. (2007b) reported that 7.8% of cows were clinically lame (≥3) and the lameness prevalence ranged from 0 to 22.4% for the individual herds during the summer.

We observed that 8.6% of cows had a mild hock lesion, 3.1% severe lesions during fall; 11.5% mild lesion, 3.5% severe lesion during spring; 14.1% mild lesion, 5.3% severe lesion during summer; and 8.0% mild lesion, 3.3% severe lesion during winter. Overall, 10.5% of cows had a mild lesion and 3.8% had a severe lesion. Barberg et al. (2007b) reported 25.1% of cows had a hock lesion, with 24.1% having hair loss (mild lesion) and 1.0% having a swollen hock (severe lesion). Both of these study results for lameness and hock lesion prevalence indicate good foot and leg health in compost barns independent of bedding material.

Table 10 shows the DHIA results for each season and farm. Farm E and F had high somatic cell counts for all seasons. Summer had the highest SCC for all farms. Barberg et al. (2007b) found an average SCC of 325,000 cells/mL (range 88,000 to 658,000 cells/mL) during the summer. For our summer measurements, we observed a range of 224,000 to 729,000 cells/mL, which was higher than Barberg et al. (2007b) observed. We could not investigate the reason herds in the current study had greater SCC, but factors such as pack stocking density and milking protocols could influence this measurement. Milk (kg), fat %, and protein % all seemed consistent among seasons. Barberg et al. (2007b) reported milk fat % of 3.77 and 3.13% for milk protein, which appear similar to our findings. Table 11 summarizes bedding, environmental and cow measurements across farms, and seasons.

Conclusions

Based on the results of this descriptive study, the alternative bedding materials used in the barns appeared to work similarly to sawdust. Pack temperatures indicated that all of the bedding materials were able to support microbial activity and produce heat. Pack chemical characteristics with alternative bedding materials were similar to those using

Table 7. Feed bunk (FB) and compost pack (CP) environmental characteristics in six compost dairy barns in Minnesota.

Season Item	Farm A FB	A CP	B FB	B CP	C FB	C CP	D FB	D CP	E FB	E CP	F FB	F CP
Winter												
Ammonia (ppm)	2.5	2.7	0.0	4.1	2.5	2.7	1.9	3.5	2.3	4.1	6.7	10.1
Hydrogen sulfide (ppb)	24	37	5	63	45	49	7	26	25	52	139	248
Light intensity (lux)	7,059	822	20,376	362	1,127	384	3,979	397	366	2,840	152	197
Air velocity (m/s)	0.37	0.21	0.98	0.14	0.67	0.25	n/a	n/a	0.69	0.47	0.25	0.12
Spring												
Ammonia (ppm)	4.8	6.8	3.2	3.4	3.0	5.4	0.6	0.7	3.3	3.8	4.6	5.5
Hydrogen sulfide (ppb)	16	25	11	12	6	14	n/a	n/a	11	23	5	12
Light intensity (lux)	1,992	1,634	3,981	193	2,344	1,750	2,790	228	1,490	980	125	150
Air velocity (m/s)	0.64	0.90	0.83	0.48	1.68	1.80	1.45	0.19	0.49	0.42	0.24	0.29
Summer												
Ammonia (ppm)	2.3	4.2	4.6	5.0	3.9	6.9	3.7	4.9	4.2	4.6	6.7	7.5
Hydrogen sulfide (ppb)	8	23	4	2	8	16	6	23	5	7	139	51
Light intensity (lux)	2,178	1,106	11,053	614	2,071	1,341	10,908	554	1,313	1,233	249	628
Air velocity (m/s)	0.49	1.13	1.40	1.10	0.60	1.35	0.66	1.62	0.39	0.46	0.58	1.42
Fall												
Ammonia (ppm)	4.3	4.4	3.6	3.0	2.4	4.4	3.3	3.5	2.5	3.4	3.0	3.4
Hydrogen sulfide (ppb)	1	0	8	12	7	22	6	14	9	15	13	24
Light intensity (lux)	932	360	33,198	616	1,251	717	22,323	657	901	999	418	154
Air velocity (m/s)	0.58	0.54	0.92	0.43	1.44	0.49	1.46	1.16	1.59	1.13	0.38	0.40

Table 8. Body condition (BCS) and hygiene scores (HS) in six compost dairy barns in Minnesota.

Season Farm	BCS	HS
Winter		
A	2.96	3.8
B	3.03	2.9
C	2.89	3.4
D	3.06	2.2
E	3.11	2.9
F	3.18	3.6
Spring		
A	2.82	2.9
B	3.00	2.8
C	3.02	3.0
D	3.16	2.3
E	3.26	3.0
F	3.19	3.0
Summer		
A	2.88	3.6
B	2.91	2.9
C	2.81	3.3
D	3.05	3.1
E	3.05	2.4
F	3.16	3.1
Fall		
A	2.90	3.5
B	2.92	3.1
C	3.01	2.9
D	3.07	2.8
E	3.05	2.9
F	3.09	3.4
Average[a]	3.03	3.1

[a] Average across seasons and farms.
HS (1 = clean, 5 = dirty).
BCS (1 = thin, 5 = obese).

Table 9. Lameness and hock lesion prevalence in six compost dairy barns in Minnesota.

Season Farm	Prevalence of Lameness (%)		Prevalence of Hock Lesion (%)	
	Lame	Severely Lame	Mild Lesion	Severe Lesion
Winter				
A	13.6	6.1	9.8	12.0
B	6.3	1.8	4.5	0.0
C	6.1	2.4	3.4	3.4
D	1.1	3.3	17.8	3.3
E	2.63	0.0	13.7	1.4
F	16.1	5.7	4.2	0.0
Spring				
A	12.2	3.1	15.0	11.0
B	8.0	0.9	5.6	0.9
C	4.6	2.3	14.9	4.6
D	18.4	2.6	25.0	1.3
E	6.2	0.0	9.7	1.4
F	9.1	3.3	6.1	1.0
Summer				
A	11.4	3.36	16.3	12.8
B	4.2	1.7	6.9	2.6
C	6.7	1.1	11.1	4.4
D	25.3	3.6	16.9	6.0
E	6.9	2.8	13.5	2.7
F	9.5	0.5	17.3	2.2
Fall				
A	10.5	6.5	12.2	9.6
B	4.5	0.0	4.5	0.9
C	5.9	0.0	14.1	2.3
D	7.4	2.1	4.3	4.3
E	5.8	0.0	1.4	0.0
F	6.9	1.1	10.4	0.0
Average[a]	9.1	2.5	10.5	3.8

[a] Average across seasons and farms.

sawdust. Most dairies preferred to use sawdust rather than the alternatives if it was available. Therefore the alternative materials only partially substituted for sawdust, except for farm C that used only strawdust. Cow comfort measurements, such as lameness and hock lesion prevalence, were similar to the previous study with herds using only sawdust. The results of this study suggest that the bedding material used is only one aspect for making compost dairy barn housing systems work. Our observations indicate that good pack management is essential. Pack moisture content in the top 15 cm should ideally be monitored weekly to decide when clean bedding needs to be added to the pack. Our observations indicate moisture content should be kept below 65%. Producers used a more practical approach of adding new material if they noticed bedding was starting to adhere to the cows. This procedure seemed to work reasonably well on most farms. We suggest that excellent milk preparation procedures are needed to maintain low somatic cell counts, especially because there is high exposure to mastitis pathogens in the bedding pack. Study results indicate that air quality in the study compost dairy barns was well below concentrations of concern even when the curtain sidewalls were covered during winter. Ventilation appears to be very important to keep the surface dry and to remove excess heat from the pack.

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References

Barberg, A. E., M. I. Endres, and K. A. Janni. 2007a. Compost dairy barns in Minnesota: A descriptive study. *Appl. Eng. in Agric.* 23(2): 231-238.

Barberg, A. E., M. I. Endres, J. A. Salfer, and J. K. Reneau. 2007b. Performance and welfare of dairy cows in an alternative housing system in Minnesota. *J. Dairy Sci.* 90(3): 1575-1583.

Table 10. DHIA lactation records in six compost dairy barns in Minnesota.

Season Farm	DIM	Milk (kg/day)	Fat (%)	Protein (%)	FCM[a] (kg/day)	SCC[b] ('000's)
Winter						
A	196	38	3.53	3.08	37.9	270
B	141	34	3.71	2.90	34.9	418
C	232	34	4.25	3.35	37.2	165
D	251	29	4.27	3.46	32.2	217
E	192	31	4.15	3.34	34.0	665
F	197	30	4.31	3.40	33.6	521
Spring						
A	184	41	3.23	2.98	39.5	248
B	181	33	3.41	2.89	31.8	218
C	166	38	3.54	3.02	37.9	128
D	232	33	4.01	3.26	34.9	176
E	196	32	4.21	3.10	35.4	756
F	206	30	4.10	3.25	33.1	706
Summer						
A	179	38	3.53	3.00	38.1	286
B	180	32	3.59	2.93	31.8	419
C	178	34	3.69	2.79	34.9	379
D	189	37	3.89	2.96	39.0	225
E	223	29	3.64	2.89	29.5	729
F	199	32	3.68	3.18	32.7	605
Fall						
A	201	39	3.57	3.05	39.0	415
B	169	30	3.55	2.92	30.8	253
C	196	34	4.08	3.23	36.3	216
D	163	33	4.16	3.10	35.8	211
E	238	32	4.12	3.31	34.0	954
F	191	29	3.98	3.31	30.8	605
Average[c]	194	33	3.83	3.13	25.6	425

[a] FCM = fat corrected milk.
[b] SCC = somatic cell count.
[c] Average across seasons and farms.

Table 11. Overall characteristics for six compost barns in six compost dairy barns in Minnesota (across seasons).

Item	Mean	Stdev.	Min.	Max.
Environmental Characteristics				
Ammonia (ppm)	3.9	2.1	0.0	13.0
Hydrogen sulfide (ppb)	23	52	0	820
Light intensity(lux)	3,252	8,330	7.53	63,484
Air velocity (m/s)	0.81	0.81	0.01	6.45
Bedding Characteristics				
Total carbon (%)	15.8	3.02	10.3	24.3
Total nitrogen (%)	0.93	0.24	0.54	1.70
C:N ratio	17.8	4.51	8.49	34.0
Total DM (%)	37.3	6.27	26.1	52.9
NO_3-N (mg/kg)	4.25	9.20	1.20	64.6
NH_4-N (mg/kg)	955	433	184	1,975
Total K (mg/kg)	14,977	5,181	5,192	26,099
Total P (mg/kg)	2,793	802	1,208	4,669
E.C. (dS/m)	8.54	3.31	3.10	16.4
Pack temperature (°C)	31.7	10.9	0.00	58.9
pH	8.8	0.2	8.4	9.3
Total bacteria counts (000,000cfu/mL)	9.42	11.11	0.157	66.92
Cow Measurements				
Body condition score	3.03	0.36	1.75	4.86
Prevalence of lameness (%)	11.6	4.82	6.10	16.7
Hygiene score	3.1	0.7	1.5	5.0
Prevalence of hock lesion (%)	14.4	6.70	6.50	24.7
Milk production (kg)	33.3	11.3	2.72	76.7
FCM (kg)	34.7	11.6	2.27	94.8
SCC ('000's)	425	1,090	13	9,999
Min. outside temperature (°C)	3.3	12.4	-30.0	22.2
Max. outside temperature (°C)	15.1	13.2	-20.6	33.9

Fassel, V. A., and R. N. Kniseley. 1974. Inductively coupled plasma optical emission spectroscopy. *Anal. Chem.* 46(9): 1110A-1120A.

Ferguson, J. O., D. T. Galligan, and N. Thomsen. 1994. Principal descriptors of body condition score in Holstein cows. *J. Dairy Sci.* 77(9): 2695-2703.

Flower, F. C., and D. M. Weary. 2006. Effect of hoof pathologies on subjective assessments of dairy cow gait. *J. Dairy Sci.* 89(1): 139-146.

Janni, K. A., M. I. Endres, J. K. Reneau, and W. W. Schoper. 2007. Compost dairy barn layout and management recommendations. *Appl. Eng. in Agric.* 23(1): 97-102.

Magnusson, M., A. Christiansson, and B. Svensson. 2007. Bacillus cereus spores during housing of dairy cows: Factors affecting contamination of raw milk. *J. Dairy Sci.* 90(6): 2745-2754.

Mitloehner, F. M., and M. S. Calvo. 2008. Worker health and safety in concentrated animal feeding operations. *J. Agric. Safety and Health* 14(2): 163-187.

Peters, R. R., L. T. Chapin, K. B. Leining, and H. A. Tucher. 1978. Supplemental lighting stimulates growth and lactation in cattle. *Science* 199(4331): 911-912.

Reneau, J. K., A. J. Seykora, B. J. Heins, M. I. Endres, R. J. Farnsworth, and R. F. Bey. 2005. Association between hygiene scores and somatic cell scores in dairy cattle. *JAVMA* 227(8): 1297-1301.

Russelle, M. P., K. M. Blanchett, G. W. Randall, and L. A. Everett. 2009. Characteristics and nitrogen value of stratified bedded pack dairy manure. Online. *Crop Management* doi:10.1094/CM-2009-0717-01-RS.

Sparks, D. L., and J. M. Bigham, eds. 1996. Methods of soil analysis: Part 3. Chemical Methods. Madison, Wis.: ASA, SSA.