COMPOST DAIRY BARNS IN MINNESOTA: A DESCRIPTIVE STUDY

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ABSTRACT. *Compost barns have been receiving increased attention as an alternative housing system for dairy cattle. The first compost dairy barn was built in Minnesota in 2001 by a producer with the goal of improving cow comfort, cow health and longevity, and ease of completing daily chores. A descriptive study was conducted from June 2005 to September 2005 on 12 compost barns in Minnesota in order to describe the building layout, collect building dimensions, characterize the bedding material, and observe barn management practices that were used on these dairies. The layout of the compost barn typically consisted of a large bedded pack surrounded by a 1.2-m concrete wall and a concrete feed alley. Walkways allowed cows and equipment to freely access the pack from the feed alley. The bedded pack was aerated twice a day. The average pack (resting) area of the 12 compost barns was 8.6 (±2.6) m^2 per cow. Bedding temperatures averaged 42.5°C (±7.6). Bedding material contained 2.54% (±0.59) N, 19.5 (±7.5) C:N ratio, 3247 (±1067) ppm P, and 15,270 (±4830) ppm K. The bedding temperatures and chemical characteristics indicate that the bedding material was not composting, however, the aerated pack was biologically active. The largest concern expressed by the producers was the cost and availability of bedding, especially as additional compost dairy barns are built. Overall, producers were very satisfied with their choice in housing system.*

Keywords. *Dairy, Housing, Compost, Bedding.*

Compost dairy barns are an alternative loose-housing system. The first compost barn in Minnesota was built by a producer in 2001. The objectives of this study were to 1) describe compost dairy barns in Minnesota, 2) determine why and when producers built their compost barn, 3) identify barn management practices utilized, 4) survey producer satisfaction with their compost barn, and 5) identify areas of concern and topics for future research.

This article focuses specifically on the use of compost barns by a subset of 12 Minnesota dairies that had been using compost barns as their primary type of housing for several months prior to the start of the study in June 2005. A literature review did not find any other study or survey that has been conducted on compost dairy barns. A companion article summarizes the history of compost barns in Minnesota and current layout and management recommendations (Janni et al., 2007).

MATERIALS AND METHODS

This study was conducted on 12 Minnesota dairy farms that used compost barns for housing milking cows. Farms were visited twice between late June and early September 2005. Farms were selected based upon barn occupancy dates provided by Extension Educators. Letters of invitation were sent to 12 producers that fulfilled the qualifications of occupancy date (at least 6 months prior to our visit) and utilizing the barn for their milking herd. A questionnaire was given to the producer during the initial on-farm visit and collected on the second visit. The questionnaire was designed to gather information about the barn management practices used and building layout, as well as farmers' satisfaction and recommendations for other producers desiring to build this type of facility. Data collected and examined included: building dimensions and layout, occupancy date, building cost, bedding type, bedding temperature and chemical analysis at two depths, feeding area, manure management, lying area space per cow, cooling methods, bedding surface bacterial concentrations, and temperature-humidity index inside and outside the barns. On-farm data were collected twice, one week apart, on each dairy operation.

BUILDING LAYOUT

The compost barn measurement and layout information collected included: barn and pack dimensions, feed alley length, waterer location and size, fan and light location and number, as well as other barn specifications.

BEDDING MATERIAL ANALYSIS

Chemical Analysis

Each compost barn pack was subdivided into 12 equal areas from which 1-L bedding samples were collected and pack temperatures measured. Bedding samples were taken at two depths (15 and 30.5 cm) in each area with an 8.3-cm hand-operated soil auger (AMS Standard Soil Auger Bucket model #77427, AMS, Inc., American Falls, Ind.). Each sample was refrigerated upon collection and later frozen at

Submitted for review in July 2006 as manuscript number SE 6594; approved for publication by the Structures & Environment Division of ASABE in November 2006.

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-40°C in the lab until drying and further analysis. Samples were dried in a 60°C oven for 24 h and ground in a stein mill for several minutes prior to analysis. Samples were further dried to obtain absolute dry matter by drying in a 100°C oven for 24 h. In both cases, samples were not allowed to cool before weighing. Bedding samples were analyzed for pH, total C, N, P, K, and electrical conductance (soluble salts) concentrations. Sub-samples from five farms were not dried and were used for ammonia analysis.

Chemical analysis of the bedding material samples was conducted by the University of Minnesota Soil Testing and Analytical Lab. Ammonia concentrations were determined by shaking 3 g of moist sample with 30 mL of 2 M KCl for 30 min. The extract was analyzed for ammonia colorimetrically on an Alpkem RFA 300 at 660 nm (Sparks and Bigham, 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 and Bigham, 1996). The pH was determined on a 1:1 sample/water mixture measured on a Beckman pH meter with glass and calomel reference electrodes calibrated to buffers pH 4 and 7 (Sparks and Bigham, 1996). The electrical conductance (soluble salts) 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 mmhols/cm (Sparks and Bigham, 1996). Total N was determined by the DUMAS combustion method using a LECO 528 analyzer (Sparks and Bigham, 1996). Total P and K were analyzed by Inductively Coupled Plasma Atomic Emission Spectrometry (ARL (Fisons) Model 3560 ICP-AES) (Fassel and Kniseley, 1974).

Bacterial Analysis

Samples were collected for bacterial analysis from the 12 areas described previously. A composite of four bedding surface samples were collected within each of the 12 areas immediately prior to milking time. The bedding samples were immediately refrigerated upon collection and later frozen at -40°C in the lab until further analysis by the University of Minnesota Laboratory for Udder Health. The samples were thawed in a refrigerator. Fifty cubic centimeters of bedding material was measured using a sterile container and placed into a Whirl-Pak® bag (Nasco, Fort Atkinson, Wis.). Two hundred fifty cubic centimeters (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 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), streptococcus species (growth on TKT agar), and coagulase negative staphylococci (growth on the CNA agar and catalase activity). Bacteria counts are expressed as colony forming units (cfu)/cc of bedding sample.

Free Air Space

Samples of the bedded pack were collected at two different depths (approximately 15 and 30 cm) in four different locations across the pack in order to determine the amount of free air space. The method utilized was modified from the Five Gallon Bucket Test by Rosen et al. (2000). Samples were collected using the soil auger described previously. The container was filled with incremental quantities of bedding material. After the addition of each amount, the container was tapped from a level of approximately 15 cm on a hard, flat surface five times. Measured quantities of water were slowly added to the container containing the bedding material until a drop of water appeared at the draining holes near the top of the container. The percent free air space was determined by calculating the volume of water added to the total volume of the container.

Temperatures

Pack temperatures were taken at each of 12 locations across the pack twice, one week apart, at various depths (15, 30.5, 61, and 91 cm) with an Omega compost thermometer (91-cm length, accuracy of ±1°C; Omega Engineering, Inc., Stamford, Conn.).

The temperature-humidity index (THI) of the environment and the barn was documented throughout the sampling week on each farm. The THI was recorded inside each barn by with a data logger centrally located in each barn at approximately 2 m above the pack surface (Temperature accuracy ±0.5°C; RH accuracy ±3%; Hobo® H8 Pro Series, Bourne, Mass.). The outdoor THI was obtained from the weather station located closest to each barn (The Weather Channel). The ambient temperature and RH were determined for each half-hour period inside of the barns and every hour for the weather and were used to calculate THI. The equation used for THI was:

$$\text{THI} = td - (0.55 - 0.55RH)(td - 58) \qquad (1)$$

where the td is the dry bulb temperature in °F and RH is relative humidity expressed as a decimal (NOAA, 1976as reported by West et al., 2003). The average THI of the barn and outdoors were calculated for the week between each visit.

Results

Twelve dairy farms in Minnesota met the selection criteria and agreed to participate in our descriptive study of compost barns for dairy cattle. The average herd size in the study was 73 (±35.5) cows, ranging from 38 to 177 cows. The DHIA rolling herd average was 10,457 (±1138) kg and the somatic cell count was 325,000 (±172,000) cells/mL for the DHIA test nearest to the date of the farm visit. One farm, J, had two compost barns of similar dimensions and cow numbers so data were reported as one farm. A majority of the barns were built similar to a freestall barn (NRAES-76, MWPS, 2000) with the intention of being able to install freestalls if the bedded pack system did not satisfy their housing needs.

Building Layout

In general, the compost barns had either an indoor or outdoor concrete feed alley, a bedded pack (resting) area that was aerated twice daily, and a 1.2-m high wall surrounding the pack (fig. 1; table 1). Two barns, E and M, had 0.6-m high perimeter walls around the outside. The wall separating the pack and the feed alley had one to four walkways for cows and equipment to access the pack. This wall was 1.2-m tall and typically of poured concrete construction. A few farms installed wire cables above the wall to prevent cows from falling or jumping onto the feed alley. The aerated pack (resting) area had an average space of 8.6 (±2.6) m^2 (92.8 ft^2) per cow (table 2). The suggested minimum space per cow in these housing systems is 7.4 m^2 (80 ft^2) for a 540 kg cow (Janni et al., 2007). A few producers were providing 9.4 m^2 per cow (100 ft^2 per cow), which is the original cow density used in Virginia compost barns (Wagner, 2002). All packs were bedded upon a clay base. Barns A and G had a divided bedded area, therefore, only the portion of the pack that housed the milking herd was utilized for all measurements. The other area of pack was used to house dry cows. Barn F was an L-shaped pack; two areas are described in order to give a complete pack area (table 2). Barn H was a drive-thru barn with four separate packs for separate groups of milking cows. Each pack was built to house 50 cows.

The type of barn construction varied, including curtain-sided wood or steel-framed pole sheds and hoop barns with wood or steel frames. Side wall height ranged from 3.7 to 4.9 m (table 1). Most barns had open sidewalls with curtains. Height of sidewall is important to provide adequate natural ventilation of the barn (MWPS-7, 2000).

Waterers were mainly located along the feed alley (table 3). Ten of the barns had waterers located adjacent to the concrete wall separating the pack area and the feed alley or on the side of the feed alley. Two farms, C and J, had water tanks outdoors on a concrete lot or pasture. Barn F also had a waterer located adjacent to the wall within the bedded pack.

The barns were equipped with a variable number of mixing fans above the pack and feed alley (table 4). Five

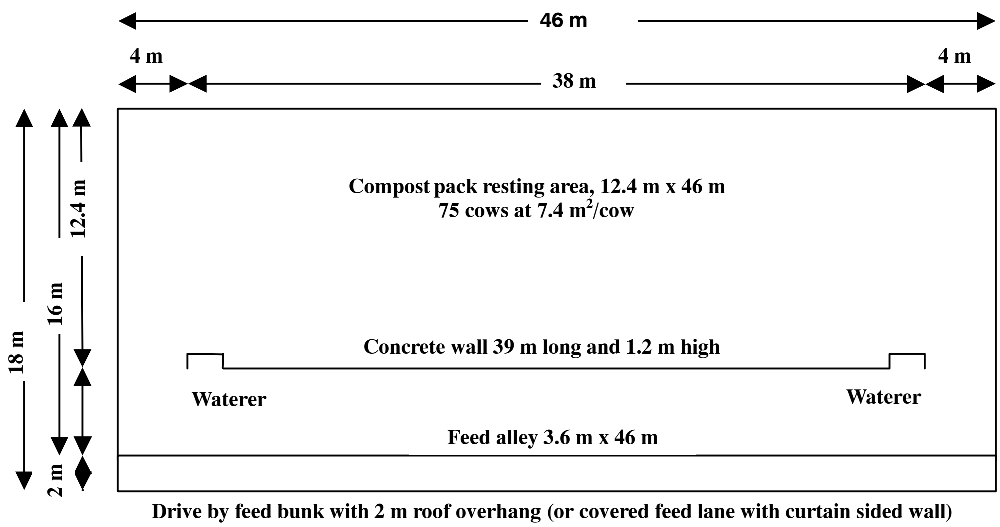

Figure 1. Compost dairy barn layout (not to scale) for 75 cows with two walkways, drive-by feeding and 2-m overhang. Waterers are against the concrete wall separating the compost bedded pack area from the feed alley and are accessed from the feed alley only.

Table 1. Compost barn dimensions and month and year cows were moved into the barn on 12 dairy farms in Minnesota.

Barn	Width, m (ft)	Length, m (ft)	Sidewall Height, m (ft)	Ridge Opening Width, cm (in.)	Occupied Month & Year
A	14.6 (48)	31.7 (104)	4.2 (13.9)	15.2 (6)	October 2004
B	12.2 (40)	41.5 (136)	4.9 (16)	38.1 (15)	December 2004
C	14.6 (48)	39.0 (128)	4.9 (16)	30.5 (12)	December 2004
D	23.2 (76)	46.3 (152)	4.9 (16)	35.6 (14)	September 2004
E	10.4 (34)	18.9 (62)	3.7 (12)	15.2 (6)	December 2003
F	19.8 (65)	70.1 (230)	3.8 (12.5)	25.4 (10)	December 2004
G	15.9 (52)	43.9 (144)	4.3 (14)	38.1 (15)	October 2001
H	29.9 (98)	95.1 (312)	4.9 (16)	61.0 (24)	November 2003
I	17.4 (66)	61.0 (200)	4.9 (16)	33.0 (13)	September 2003
J	12.8 (42)	36.6 (120)	3.8 (12.5)	15.2 (6)	December 2003
L	24.4 (80)	91.5 (300)	4.9 (16)	45.7 (18)	March 2005
M	18.3 (60)	68.3 (224)	4.3 (14)	30.5 (12)	September 2003

Table 2. Compost barn pack dimension, cow numbers, and pack space per cow for 12 dairy farms in Minnesota.

Barn	Compost Pack Area, m × m (ft × ft)	Cows	Pack Area, m^2/cow (ft^2/cow)
A	15 × 24 (48 × 80)	50	7.1 (76.8)
B	12 × 41 (39 × 136)	60	8.2 (88.4)
C	15 × 39 (48 × 128)	60	9.5 (102.4)
D	15 × 46 (48 × 152)	93	7.2 (78.5)
E	7 × 18 (24 × 60)	38	3.5 (37.9)
F	10 × 35 and 20 × 35 (32.5 × 115 and 65 × 115)	75[a]	14.3 (153.6)
G	12 × 34 (40 × 112)	60	7.0 (75)
H	8.5 × 44 (28 × 144)	45/pen	8.3 (90)
I	16 × 61 (52 × 200)	80[b]	10.7 (115)
J	9.8 × 34 (32 × 112)	31	10.8 (116)
L	15 × 34 (50 × 112)	62	8.4 (90.3)
M	9.8 × 54 (32 × 176)	64	8.2 (88)

[a] Built for 125 cows.
[b] Built for 100 cows.

Table 3. Feed manger and waterer information for 12 compost dairy barns in Minnesota.

Barn	Manger Information	Waterer Information
A	24.4-m (80-ft) long outdoor uncovered drive-by	Two 0.6-m (2-ft) waterers outside on feed alley
B	39-m (128-ft) long drive-by with 1.2-m (4-ft) overhang	One 1.8-m (6-ft) waterer outside on feed alley
C	42.7-m (140-ft) long outdoor uncovered drive-by	Outside on concrete lot and pasture
D	46-m (150-ft) long covered drive-by	One 3.6-m (12-ft) and two 2.4-m (8-ft) waterers by wall between pack and feed alley
E	13.4-m (44-ft) long covered drive-by	One 0.9-m (3-ft) waterer inside by feed alley
F	27-m (88-ft) long feed bunk accessed on both sides	Two 3-m (10-ft) waterers in feed bunk area and one 1.8-m (6-ft) waterer by wall in the pack area
G	32-m (104-ft) long drive-by with 1.8-m (6-ft) overhang	One 3.6-m (12-ft) waterer inside adjacent to feed manger
H	41-m (136-ft) manger per pen with center drive through feed alley	Two water fountains per pen by wall between pack and feed alley
I	61-m (200-ft) long drive-by with 1.8-m (6-ft) overhang	Three 1.5-m (5-ft) water troughs inside by wall between pack and feed alley
J	34-m (112-ft) long drive-by with overhang	One 150-L (40-gal) fountain by wall between pack and feed alley and 5400-L (900-gal) tank outside
L	40-m (130-ft) long covered drive-by	Two 2-m (7-ft) waterers per pen by the wall between the pack and feed alley
M	54.9-m (180-ft) long covered drive-by	Two 0.6-m (2-ft) waterers inside by the wall between the pack and feed alley

Table 4. Mixing fan number, size and location for 12 compost dairy barns in Minnesota.

Barn	Mixing Fan Number, Size and Location
A	Six 91-cm (3-ft) diameter fans inside at eaves blowing North and downward on the pack
B	No fans
C	No fans
D	Eight 1.3-m (52-in.) diameter fans over the feed alley blowing North and over the pack
E	Five ceiling fans hanging from the eves over the pack and feed alley blowing downward
F	Four 7.3-m (24-ft) diameter high volume low speed fans distributed uniformly over the entire barn
G	Eight 91-cm (3-ft) diameter fans inside at eaves blowing north and downward on the pack
H	Nine 91-cm (3-ft) diameter fans per pen blowing North and downward on the pack
I	Six 122-cm (4-ft) diameter stir fans along feed alley over the pack
J	No fans
L	No fans
M	Three 7.3-m (24-ft) diameter high volume low speed fans distributed uniformly over the entire barn

farms utilized only natural ventilation. Ridge opening widths ranged from 15 to 61 cm, varying with barn dimensions (table 1). Seven of the barns had an open ridge width built according to the recommendations of the MidWest Plan Service (MWPS-7, 2000). The remaining barns did not have ridge openings as wide as recommended for the width of the barn.

Lighting in the compost barns was similar to that used in freestall barns (MWPS-7, 2000). Most barns utilized extended day lighting with metal halide or mercury vapor lights. However, barns B and J were not wired for lighting.

Bedding

The compost barns in this study were bedded with dry fine wood shavings or sawdust. According to the questionnaire responses, a semi-load (approximately 14 metric tons) of bedding was added every two to five weeks, varying by season, weather conditions, and cow density. Fresh bedding was added when the bedding particles became moist enough to adhere to the cows. Initially 25 to 50 cm of loose dry fine wood shavings or sawdust was put down to start the compost pack. One farm initially put a layer of long straw on the clay prior to adding sawdust. Normally the amount of bedding added at a time from a semi-load of sawdust provided 10 to 20 cm of fresh bedding across the pack. However, two producers, barns A and E, added less bedding more often, up to twice per week.

The bedded pack was aerated twice a day while the cows were being milked. The pack was aerated to a depth of 18 to 24 cm, which is less than the recommended depth of 25 to 30 cm (Janni et al., 2007). Aerating was most often done with a modified cultivator on a skid loader or small tractor. However, farm A used a manure fork on the front of a skid loader to aerate the pack, and farm F utilized a roto-tiller behind a small tractor. Aerating the pack incorporated manure and urine on the lying surface into the bedded pack in order to provide a cleaner lying surface for the cows returning from milking.

Aerating the pack introduced air into the top layer of the pack, possibly increasing the percent of free air space. The average free air space was greater in the top 15 cm of each of the bedded packs than in the lower 15 to 30 cm. Paired t-test statistical analysis indicated that these two averages were different ($P < 0.01$). The average free air space was 70.8% (±4.6%) in the top 15 cm with a minimum of 55.0% and a maximum of 88.0%. Between 15 and 30 cm the average free air space was 65.3% (±5.2%), with a minimum of 56.0% and a maximum of 74.0%. However, the technique used may be more of an indication of a difference in particle size and shape rather than the amount of air space in the undisturbed pack.

The average bedding temperature across all depths, across all pack barns was 42.5°C (±7.6). The minimum temperature was 24.4°C and the maximum was 58.9°C. The first and third quartiles were 37.4°C and 47.8°C, respectively. The temperatures did not vary significantly across depths in each barn so the temperatures at both depths were combined. Table 5 highlights the variation across the individual packs of each barn. Only six areas were sampled in barn E because it had a smaller pack area than the other barns (table 5). The pack surface temperatures were similar to the ambient temperature. Temperatures tended to be lower on farms A, E, and M, which utilized large particle wood shavings rather than sawdust for bedding. Additionally, temperatures were lower for farm C which had a herd of cows that spent a majority of

Table 5. Average bedding temperatures (°C) in 12 different locations in 12 compost barns in Minnesota and the weekly average THI in the barn and outside during the week of observation.

Barn/ Area	1	2	3	4	5	6	7	8	9	10	11	12	THI Barn[a]	THI W[b]
A	28.8	27.9	32.6	33.3	29.1	30.8	38.5	34.9	29.6	34.4	35.0	36.7	83.8	82.1
B	46.1	47.8	46.1	49.9	43.1	48.3	47.4	50.3	46.4	45.6	43.2	45.3	80.8	76.3
C	30.0	30.8	30.9	28.4	34.9	34.6	29.2	28.1	38.1	31.5	28.2	26.9	81.3	76.3
D	47.7	53.3	51.5	50.5	47.3	51.6	46.7	45.1	50.0	43.2	49.7	48.0	86.0	85.1
E	37.7	36.2	41.9	42.1	41.5	48.3							82.9	82.7
F	49.9	51.3	51.1	50.7	54.8	49.3	49.0	49.6	47.6	49.2	52.5	48.1	72.2	69.8
G	47.6	43.4	43.9	48.5	47.8	47.8	41.2	47.5	48.9	47.1	37.5	37.9	71.6	69.8
H	43.8	46.4	46.5	44.4	45.8	50.3	43.1	47.2	40.9	34.7	37.8	34.9	70.9	70.0
I	40.3	40.7	43.9	47.1	50.7	34.7	41.1	48.9	46.3	45.2	37.6	31.5	N/A	70.0
J	45.0	41.1	46.7	40.8	41.7	38.3	39.3	45.0	42.4	37.2	41.0	38.3	73.8	71.8
L	39.3	44.9	45.2	43.1	44.3	43.5	46.0	45.0	45.7	46.0	45.2	41.7	N/A	65.5
M	28.5	26.3	39.9	39.3	30.0	39.4	40.3	30.6	32.5	40.6	34.6	35.2	65.9	65.5

[a] THI Barn is the temperature-humidity index inside of the barn.
[b] THI W is the temperature-humidity index of the environment outside of the barn.

time on pasture or a concrete lot in the summer months. Temperatures were greater in the areas of the pack that were fluffier, that were not as heavily soiled or packed by the cows. This observation is consistent with the need for oxygen and air for microbial activity that promotes composting (NRAES-54, 1992). The ideal temperature for composting is between 54°C and 60°C; however 43°C to 65°C is considered reasonable for composting (NRAES-54, 1992).

The weekly average THI was similar inside the barn to the weekly average THI from the local weather station reports (table 5). It has been found that a THI greater than 72 negatively affects the health and milk production of dairy cows (Igono et al., 1992), indicating that the cows are under heat stress.

The moisture content of the bedding material ranged from 28.0% to 78.9% wet basis across two depths in 12 locations in all barns (table 6). Paired t-test statistical analysis indicated that the averages for the two depths were different ($P < 0.01$). When comparing the moisture contents of the two depths, it was found that the average of the top 15 cm [50.7% (±8.8%)] was less than the average of the lower 15 to 30 cm [56.7% (±8.8%)]. The average moisture content across all barns was 54.4%, within the recommended range for composting of 50% to 60% moisture (NRAES-54, 1992). The moisture content varied based upon time since last addition of fresh bedding, weather and cow density in the sampling area.

Table 6. Moisture content (%) of sawdust bedding at two depths in 12 compost barns in Minnesota.

Barn	Average	Std Dev	Min.	Max.	1st Quartile	3rd Quartile
All barns	54.4	9.1	28.0	78.9	48.4	61.6
All barns 15 cm	52.7	9.0	28.0	78.9	47.5	59.6
All barns 30 cm	56.7	8.8	32.0	66.6	53.6	62.4
A 15 cm	60.8	2.3	56.3	64.6	59.0	62.6
B 15 cm	51.5	5.4	44.0	59.6	47.8	55.3
B 30 cm	58.4	5.0	48.8	66.6	56.4	61.4
C 15 cm	62.4	1.8	58.7	65.8	61.1	64.1
C 30 cm	64.3	2.6	58.3	66.1	64.2	65.5
D 15 cm	48.8	6.3	40.6	63.8	46.7	53.1
D 30 cm	59.9	4.0	52.5	65.6	58.0	62.5
E 15 cm	54.8	10.3	42.0	78.9	46.6	59.7
F 15 cm	36.5	5.0	30.7	47.7	32.3	38.4
F 30 cm	40.6	6.8	32.0	53.6	36.1	44.6
G 15 cm	50.5	5.6	42.8	59.4	46.1	54.7
G 30 cm	58.3	7.0	39.5	64.7	56.9	62.5
H 15 cm	53.0	5.9	45.0	64.0	48.3	54.5
H 30 cm	57.6	6.5	44.2	64.6	57.7	61.1
I 15 cm	49.6	4.4	40.7	54.8	47.0	52.7
I 30 cm	48.5	8.8	35.2	61.1	40.7	56.2
J 15 cm	46.3	11.2	28.0	62.4	40.9	53.8
J 30 cm	60.2	2.4	55.0	62.2	60.1	61.7
L 15 cm	56.6	2.9	50.0	60.9	55.4	57.9
L 30 cm	62.6	0.9	61.6	63.9	61.7	63.6
M 15 cm	59.2	4.7	50.0	65.0	56.0	63.1

Chemical Analysis

Tables 7, 8, 9, and 10 include the average, standard deviation, minimum, maximum, and first and third quartile values of N, C:N, P, and K content of the bedding material in 12 compost barns in Minnesota. Each average value is an average of the 12 samples collected at a particular barn and pack depth. Data from one depth only is reported for barns A, E, and M, as the pack was not deep enough for sampling two depths. The average total N of the bedding material in all compost barns was 2.54% with a range of 0.57% to 4.22%; the average P was 3247 ppm with a range of 378 to 6668 ppm; and the average K was 15,270 ppm with a range of 2568 to 29,570 ppm. These compare to typical manure of lactating dairy cattle consisting of 5.1% N, 8764 ppm of P, and 11,573 ppm of K (*ASAE Standards*, 2005). Sawdust, on average, has an N content of 0.24% (NRAES-54, 1992). The average carbon to nitrogen (C:N) ratio of all barns in all locations and depths was 19.5:1 with a interquartile range of 15:1 to 21.1:1, which is below the preferred range of 25:1 to 30:1 for composting (NRAES-54, 1992). A C:N ratio below 25:1 may emit ammonia odor (Rosen et al., 2000), which may influence the ammonia levels in the compost barns. The ammonia, soluble salts, and pH concentrations of the 12 compost barns are reported as an average across farms in all locations on table 11. The ammonia-nitrogen concentrations were greater deeper into the pack (14 to 28 cm), than in

Table 7. Total Nitrogen content (%) of 12 composite samples at two depths in 12 compost barns in Minnesota.

Barn	Average	Std Dev	Min.	Max.	1st Quartile	3rd Quartile
All barns	2.54	0.59	0.57	4.22	2.19	2.97
All barns 15 cm	2.45	0.55	1.50	3.27	2.16	2.81
All barns 30 cm	2.69	0.45	2.09	3.49	2.40	3.02
A 15 cm	2.77	0.14	2.47	2.93	2.73	2.87
B 15 cm	1.78	0.27	1.35	2.32	1.63	1.91
B 30 cm	2.18	0.35	1.37	2.62	2.00	2.42
C 15 cm	1.94	0.59	0.57	2.86	1.69	2.31
C 30 cm	3.49	0.32	2.96	3.89	3.30	3.82
D 15 cm	3.27	0.30	3.00	4.22	3.16	3.27
D 30 cm	3.04	0.20	2.60	3.35	2.94	3.16
E 15 cm	1.38	0.27	0.94	1.85	1.17	1.57
F 15 cm	2.34	0.11	2.16	2.52	2.26	2.42
F 30 cm	2.40	0.12	2.16	2.54	2.36	2.47
G 15 cm	2.42	0.14	2.11	2.56	2.35	2.54
G 30 cm	2.09	0.18	1.68	2.30	1.98	2.23
H 15 cm	2.94	0.21	2.70	3.27	2.78	3.10
H 30 cm	2.72	0.24	2.33	3.17	2.55	2.83
I 15 cm	2.67	0.28	2.00	2.99	2.61	2.85
I 30 cm	2.45	0.37	1.91	2.97	2.15	2.69
J 15 cm	2.29	0.43	1.75	3.15	1.96	2.51
J 30 cm	2.84	0.37	2.13	3.43	2.61	3.10
L 15 cm	3.23	0.21	2.90	3.55	3.12	3.41
L 30 cm	3.02	0.11	2.87	3.19	2.92	3.11
M 15 cm	2.24	0.14	1.96	2.55	2.18	2.28

Table 8. Carbon to nitrogen ratio content of 12 composite samples at two depths in 12 compost barns in Minnesota.

Barn	Average	Std Dev	Min.	Max.	1st Quartile	3rd Quartile
All barns	19.5	7.5	10.9	87.5	15.0	21.1
All barns 15 cm	21.4	9.4	10.9	87.5	15.7	23.1
All barns 30 cm	17.6	3.7	11.4	35.2	14.9	19.8
A 15 cm	14.6	0.5	13.6	15.6	39.5	15.0
B 15 cm	26.7	4.5	20.2	36.3	24.2	29.2
B 30 cm	21.6	4.9	17.4	35.2	18.3	23.2
C 15 cm	28.2	19.5	36.9	87.5	18.8	28.2
C 30 cm	13.0	1.0	11.4	14.6	12.3	13.6
D 15 cm	13.9	1.1	10.9	15.3	13.7	14.2
D 30 cm	15.1	1.3	13.2	18.1	14.3	15.6
E 15 cm	37.3	8.4	26.5	55.3	31.1	42.7
F 15 cm	20.0	1.4	18.0	22.8	19.1	20.9
F 30 cm	18.7	1.0	17.5	20.7	18.0	19.5
G 15 cm	20.1	1.4	18.5	23.3	19.2	20.7
G 30 cm	22.2	1.8	20.1	25.8	20.9	23.4
H 15 cm	17.2	7.9	1.4	23.3	18.7	20.5
H 30 cm	17.7	1.7	15.0	20.9	16.8	18.5
I 15 cm	17.4	2.8	15.1	24.1	15.4	18.3
I 30 cm	18.5	2.9	13.8	23.3	16.9	20.6
J 15 cm	21.9	4.4	14.5	28.8	19.0	24.9
J 30 cm	16.8	2.5	13.8	22.1	15.0	18.2
L 15 cm	13.6	1.1	12.1	15.7	12.8	14.3
L 30 cm	14.5	0.9	13.2	16.2	13.8	15.1
M 15 cm	20.1	1.4	17.7	23.3	19.3	20.6

Table 9. Total Phosphorus content (ppm) of 12 composite samples at two depths in 12 compost barns in Minnesota.

Barn	Average	Std Dev	Min.	Max.	1st Quartile	3rd Quartile
All barns	3247	1067	378	6668	2454	3975
All barns 15 cm	3111	1060	378	6668	2354	3860
All barns 30 cm	3442	1059	1227	6266	2580	4345
A 15 cm	2449	188	2152	2780	2347	2543
B 15 cm	2197	458	1422	3000	1957	2497
B 30 cm	2570	637	1244	3551	2149	3007
C 15 cm	1886	624	378	2582	1620	2353
C 30 cm	2935	699	1877	3945	2470	3477
D 15 cm	2922	283	2386	3421	2764	3075
D 30 cm	2680	502	1856	3478	2344	3035
E 15 cm	2375	631	978	3128	2048	2818
F 15 cm	4241	441	3557	4753	3927	4668
F 30 cm	4712	276	4262	5089	4524	4940
G 15 cm	2922	517	1938	3721	2602	3276
G 30 cm	3284	981	1548	4604	2541	4046
H 15 cm	4029	330	3558	4559	3852	4263
H 30 cm	3057	592	2197	3858	2716	3733
I 15 cm	3432	1558	330	4559	3632	4204
I 30 cm	4590	863	3046	6266	4217	5077
J 15 cm	2165	752	1104	3596	1632	2575
J 30 cm	2803	1065	1227	4814	2299	3150
L 15 cm	3642	575	2887	4619	3226	3942
L 30 cm	4241	415	3612	4677	3767	4577
M 15 cm	3613	266	3263	4208	3433	3677

Table 10. Total Potassium content (ppm) of 12 composite samples at two depths in 12 compost barns in Minnesota.

Barn	Average	Std Dev	Min.	Max.	1st Quartile	3rd Quartile
All barns	15,270	4830	2568	29,570	11,617	18,191
All barns 15 cm	13,831	4437	2568	26,322	10,595	17,124
All barns 30 cm	17,202	4725	6506	29,570	13,891	21,380
A 15 cm	11,228	1017	9156	12,554	10,536	12,165
B 15 cm	12,844	2353	8901	17,125	11,358	14,190
B 30 cm	15,163	2668	10,249	18,716	12,836	17,188
C 15 cm	12,647	4694	2568	20,416	10,285	14,956
C 30 cm	19,869	3908	12,882	24,246	17,390	23,204
D 15 cm	14,573	2998	9447	22,838	13,597	15,086
D 30 cm	14,116	1784	10,825	16,301	13,354	15,412
E 15 cm	10,694	3300	4683	16,261	9063	12,815
F 15 cm	16,743	1694	13,470	19,471	15,598	18,105
F 30 cm	19,655	2104	15,897	22,251	18,024	21,558
G 15 cm	8454	1182	6350	10,250	7670	9284
G 30 cm	10,863	2450	6506	15,419	9951	12,302
H 15 cm	12,246	1422	10,110	14,741	11,099	13,410
H 30 cm	15,137	1719	11,465	17,747	14,186	16,203
I 15 cm	19,403	3896	14,367	26,322	16,866	21,580
I 30 cm	23,592	3107	18,826	29,570	21,320	25,359
J 15 cm	8905	3740	3890	16,134	5094	11,032
J 30 cm	16,732	1451	13,953	18,698	15,391	17,714
L 15 cm	18,295	1963	15,699	22,556	17,108	19,204
L 30 cm	21,971	1904	17,869	24,366	21,408	23,291
M 15 cm	18,019	1711	14,789	20,833	17,014	19,355

Table 11. Chemical characteristics of 12 compost barns in Minnesota.

	Units	Average	Std Dev	Min.	Max.	1st Quartile	3rd Quartile
pH 15 cm	units	8.4	0.8	6.5	9.6	8.0	8.9
pH 30 cm	units	8.6	0.7	6.4	9.9	8.3	9.0
Soluble salts 15 cm	mmhols/cm	8.9	4.3	0.8	21.5	5.6	11.5
Soluble salts 30 cm	mmhols/cm	10.2	3.2	3.9	19.6	7.5	12.7
Ammonia 15 cm	ppm	461	274	34	1128	202	632
Ammonia 30 cm	ppm	857	457	172	1981	619	1138

the top 6 to 14 cm. The average electrical conductance was 8.9 (±4.3) mmhols/cm, below the 10 mmhols/cm maximum concentration desired for composting (NRAES-54, 1992). The average pH was 8.4 to 8.6, slightly above the recommended pH level for composting of 6.5 to 8.0 (NRAES-54, 1992).

Bacterial Analysis

Bedding samples were analyzed for pathogenic mastitis causing bacteria counts. The total bacteria counts averaged 9,122,700 (±6,171,520) cfu/cc with a range of 2,035,562 to 22,562,604 cfu/cc. These values are similar to what has been reported previously for sawdust bedding (Zdanowicz et al., 2004). Of the total bacterial counts found in bedding 10.7% were coliforms, 39.4% were environmental Streptococcus species, 17.4% were environmental Staphylococcus species, and 32.5% were Bacillus species. Bacterial counts in the bedding material are positively correlated with bacterial counts on the teat ends (Hogan and Smith, 1997; Zdanowicz et al., 2004) and the rates of clinical mastitis in lactating dairy cows (Hogan et al., 1989). Low concentrations of mastitis causing bacteria are desirable in bedding used for dairy cows. The high bacteria counts found in compost barns emphasize the importance of excellent cow preparation procedures at milking.

Manure Management

The bedded pack provided manure storage for six months to one year. A majority of producers completely emptied the bedded pack area once per year following fall harvest and spread the manure laden bedding according to their manure management plan. Some producers removed the top half of the pack in the spring in order to ensure that there would be enough bedding accumulation space in the barn for the summer months.

The concrete feed alleys were scraped twice daily. Producers estimated that 20% to 25% of total daily manure was voided in the feed alley. The stackability of the feed alley manure depended on the amount of bedding that had spilled into the feed alley. Producers handled the feed alley manure in a variety of ways. Of the 12 dairies surveyed, only two farms, C and J, had long-term storage for the feed alley manure; others utilized stacking slabs, mini-pits inside or outside of the barn, or hauled manure daily.

Building Cost

Building costs ranged from \$33,000 to \$300,000, with a cost per cow ranging from \$625 to \$1,750. The average cost per cow based upon a uniform space allowance of 7.4 m^2 per cow was \$1,200. The building costs ranged widely depending upon the amount of on-farm labor utilized and amenities added to the pack barn.

Producer Responses

Qualitative responses regarding the reasons for building and concerns for future producers to consider were similar among all producers. All producers identified cow comfort as the main reason for building a compost barn, along with increased cow longevity and ease of completing daily chores. Some producers also chose this housing system because of the reduced initial investment cost over freestalls. Overall, the producers were very satisfied with their compost barns. They observed that cows were more comfortable, had less health problems, and were able to stay in the herd longer than in their previous housing system. However, results of the survey revealed some concerns with the alternative housing system. The main concern was the rising cost of sawdust as a bedding material, particularly as additional barns are built. Many producers were seeking alternative bedding sources that will work in this housing system. Also, some producers were concerned with the dustiness of the dry sawdust. A couple of producers indicated that pneumonia and eye irritation had resulted from dusty loads of sawdust. All of the producers recommended the compost bedded pack barn for other dairymen, emphasizing that a reliable source of bedding must be located before building the alternative housing system.

Conclusions

The compost dairy barn appeared to be a suitable housing system for dairy cattle. The compost barns in Minnesota at the time of this study had a variety of building designs. Producers built compost barns for their milking herd with the main goals of improving cow comfort, cow longevity, and ease of completing daily chores. The temperature of the bedded pack was not as high as it needs to be for effective composting; however, pack temperature did indicate some microbiological activity was occurring. The goal of the producers was to provide a comfortable surface for cows to lie down, not necessarily optimize composting. However, more research is needed to identify what management practices or bedding characteristics could result in more effective composting and possible reduction of bacteria counts in bedding. Chemical analysis of the bedded pack revealed that the spent bedding material was suitable for use as a fertilizer. Results would probably differ from what was observed during summer for a number of characteristics reported in this study; therefore research is needed at other times of the year. Overall, producers were very satisfied with the housing system. Additional research is needed in order to address a main area of concern on what alternative bedding sources can be utilized in this system. In addition, the air quality of compost barns needs to be analyzed.

ACKNOWLEDGEMENTS

We would like to thank the producers for their participation and support of this descriptive study. We thank the Extension Educators, Vince Crary, Jim Salfer, and Wayne Schoper, who helped identify the cooperating producers. Additionally, we thank Dr. Thomas Halbach for the use of his soil auger and bedding sampling and testing advice and Dr. Russell Bey for advice on microbiological sample collection. This study was partially supported by a grant from the Minnesota Department of Agriculture. We appreciate their financial support.

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