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Compost Bedded Pack Barns: Management Practices and Economic Implications

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COMPOST BEDDED PACK BARNs: MANAGEMENT PRACTICES AND ECONOMIC IMPLICATIONS

________________________________________

THESIS

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Animal and Food Sciences at the University of Kentucky

By

Randi Alyson Black

Lexington, Kentucky

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2013

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ABSTRACT OF THESIS

COMPOST BEDDED PACK BARNs: MANAGEMENT PRACTICES AND ECONOMIC IMPLICATIONS

Compost bedded pack (CBP) barn design and pack maintenance procedures vary considerably, making advising and problem-solving challenging. One objective of this research was to characterize herd performance and management practices employed by Kentucky CBP managers (42 farms and 47 CBP facilities). Producer satisfaction, changes in historical bulk-tank somatic cell count, and improvement in herd performance parameters after transitioning to a CBP barn support reported CBP barn system benefits. Daily milk production increased from before moving into the CBP barn to the second year after (29.3 ± 0.3 vs. 30.7 ± 0.3 kg, respectively; \( P < 0.05 \)) for farms using the CBP barn as the primary housing facility (n = 8). Increasing stirring frequency, stirring depth, and ambient temperatures increased pack temperature. Increased drying rate decreased CBP moisture. Increased 20.3 cm depth CBP temperature and ambient temperatures improved cow hygiene. Mastitis-causing bacteria thrive in conditions similar to optimal composting bacteria conditions, making reduction of these bacteria difficult in an active composting environment. Producers must pay attention to other management areas where preventive measures can be employed. The New Dairy Housing Investment Analysis Dashboard provides users an interactive and flexible decision tool to make more informed facility investment decisions.

KEYWORDS: compost bedded pack barn, facility management, bacterial analysis, economic dashboard, cow comfort

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January 15, 2013
COMPOST BEDDED PACK BARNS: MANAGEMENT PRACTICES AND ECONOMIC IMPLICATIONS

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FREQUENTLY USED ABBREVIATIONS

CBP = Compost bedded pack
BP = Bedded pack
SCC = Somatic cell count
C:N = Carbon to nitrogen ratio
THI = Temperature humidity index
MF = Mattress base freestall
SF = Sand base freestall
BTSCC = Bulk tank SCC
CV = Cross-ventilated
NV = Naturally ventilated
RH = Relative humidity
CT= Surface and 10.2 cm pack depth mean temperature
NPV = Net present value
IRR = Internal rate of return
DR = Discount rate
PP = Payback period
BC = Breakeven barn cost
d = Day
wk = Week
mo = Month
y = Year
kg = Kilogram
lb = Pound

cwt = Hundred weight

mL = Milliliter

cfu = Colony forming units
CHAPTER ONE

Review of Literature

INTRODUCTION

Housing dairy cattle indoors and on concrete triggers consumer concern, especially related to potential lameness associated with housing cows on concrete. Dairy producers house cows using the conventional bedded pack (BP) barn with anticipation of improved animal well-being. However, risks associated with the BP system deter many producers from using the system. A newer system, the compost bedded pack (CBP) barn, attempts to alleviate many of the risks related to the BP barn, while still improving animal well-being. This literature review explores the two systems and expands on the CBP system through analysis of current research.

CONVENTIONAL BEDDED PACK BARN

In the mid-1950s, producers established a dairy cattle housing facility, which allowed cows to lie on a bedded manure pack and to be milked in a separate milking facility (Bickert and Light, 1982). Producers designed the BP barn, or straw yard, to reduce initial investment cost compared to freestall housing and provide cows with a soft, open resting area (Kammel, 2004). Figure 1.1 displays a BP barn cross-section designed by Hindhede and Enevoldsen (1993). The bedded pack area is recessed into the ground allowing bedding material accumulation. A concrete alleyway, either solid or with slats, separates the bedded pack and the feed manger, or feedway. Conventional bedded pack barns provide a large, open resting area for cows bedded with an organic material, typically straw. Because manure is deposited directly onto bedded pack surface,
maintenance of a clean, dry surface requires frequent new straw addition (Hindhede and Enevoldsen, 1993). Hindhede and Enevoldsen (1993) further explained how an increase in space per cow reduced straw demand because of less manure and urine input. They recommended at least 4 to 6 m² per cow on the bedded pack, requiring 9.7 kilograms (kg) to 13.2 kg of straw used per cow per day (d). Although fixed costs were lower, variable costs from increased bedding use increased compared to freestall housing (Hindhede and Enevoldsen, 1993, Kammel, 2004). The bedded pack does act as manure storage, though additional storage is necessary for manure accumulated in the alleyways, holding pen, and parlor (Kammel, 2004). For herds using the bedded pack as a winter housing system, typically pasture-based herds, the bedded pack material is removed at the end of the winter season. For continuously occupied barns, removal occurs every two to four months (Kammel, 2004).

Lying time is an animal welfare indicator (Fregonesi and Leaver, 2001, Krohn et al., 1992, Miller and Wood-Gush, 1991). Management and housing system influence lying time (Fregonesi and Leaver, 2001). Researchers and producers consider improved lying times and feet and leg health to be the main advantages of the bedded pack barn. Fregonesi and Leaver (2001) observed cow lying times for four different cow groups: low production cows housed on a bedded pack (LB), low production cows housed in freestalls (LF), high production cows housed on a bedded pack (HB), and high production cows housed in freestalls (HF). Cows housed in the BP barn spent more time lying down (LB = 843 min/d, LF = 814 min/d, HB = 792 min/d, HF = 711 min/d; P < 0.01), ruminating (LB = 507 min/d, LF = 468 min/d, HB = 538 min/d, HF = 473 min/d; P < 0.001), and standing or lying on the bed (LB = 996 min/d, LF = 910 min/d, HB = 961
min/d, HF = 859 min/d; \( P < 0.05 \) compared to time in freestalls. Fregonesi et al. (2009) observed similar results when allowing cows to choose between freestalls and a bedded pack. When provided a choice between the two systems, cows spent more time lying on the bedded pack (7.2 ± 0.3 h/d) than in the freestalls (5.9 ± 0.3 h/d; \( P < 0.05 \)). Additionally, 92 of 96 cows preferred to stand with all four hooves in the bedded pack compared to the freestalls. Phillips and Schofield (1994) reported that cows expressed more secondary estrus behaviors such as sniffing and licking the genital area (0.3 vs. 0.2 incidences per 30 min) and performed fewer unsuccessful mountings (0.4 vs. 0.5 incidence per 30 min) when housed on a bedded pack compared to a freestall, respectively. Better footing on the bedded pack compared to concrete likely increased cow comfort.

Some negative animal health factors have been attributed to the BP, including increased intramammary infection risk (Berry, 1998, Fregonesi and Leaver, 2001, Peeler et al., 2000). Proper cow hygiene management can reduce mastitis risk (Neave et al., 1969, Philpot, 1979, Reneau et al., 2005, Schreiner and Ruegg, 2003). Berry (1998) reported that producers housing cows on BP observed a mean clinical mastitis incidence of 38 cases per 100 cow-years (y)(number of mastitis cases per 36,500 d at risk). Increased lying time likely increased udder exposure to environmental pathogens. Fregonesi and Leaver (2001) reported that hygiene score (1.5 vs. 0.4, on a scale of 1 to 5 where 1 is clean and 5 is very dirty; \( P < 0.001 \)) and SCC (386,000 vs. 118,000 cells/milliliter (mL); \( P < 0.05 \)) were higher for cows housed on BP barns compared to freestall barns, respectively. Conversely, Barbari and Ferrari (2006) reported lower hygiene scores for cows housed in freestall barns compared to BP barns (3.31 vs. 4.47,
respectively, on a scale of 0 to 10, with 0 being clean and 10 totally covered in dirt; \( P < 0.01 \).

Conventional bedded pack barns may also negatively affect environmental conditions. Snell et al. (2003) reported higher ammonia and methane emissions for a BP barn compared to three differently constructed freestalls barns (Ammonia: 3.56 vs. 1.62, 1.68, and 2.38 g/h per cattle equivalent, respectively; Methane: 32.59 vs. 16.23, 11.13, and 14.49 g/h per cattle equivalent, respectively; where 1 cattle equivalent = 500 kg live weight). A study conducted by Mosquera et al. (2006) reported ammonia emissions of 38.1 g NH\(_3\)/cow/d in a BP barn, assuming a grazing season of 175 d, a value similar to that reported for freestall housing with slatted floors (32 to 45 g/cow/d, Kroodsma et al., 1993; 20 to 42 g/cow/d, Groot Koerkamp et al., 1998; 26 g/cow/d, Pfeiffer et al., 1994) and freestall housing with solid floors (25 g/cow/d, Pfeiffer et al., 1994; 32 g/cow/d, Demmers et al., 1998). Spiehs et al. (2010) examined volatile organic compounds emitted from bedded packs used to house beef cattle. Volatile organic compounds contribute to odor nuisance and include ammonia, volatile fatty acids, sulfur compounds, and aromatic compounds, often produced by bacteria during aerobic or anaerobic organic material digestion (Mackie et al., 1998). Volatile organic compound concentrations, except ammonia, were greater on the concrete feed alley and in the area between the feed alley and bedded pack area compared to the bedded pack area. The three areas produced similar ammonia concentrations. Therefore, ammonia concentrations in BP barns may be similar to freestalls with excessive manure buildup in alleys because freestalls would have similar concentrations to the concrete feed alley. However, depending on BP
management, the resting area in the BP may produce less odor nuisance compared to freestalls with poor alleyway manure management.

The BP barn contributes some improvements to animal well-being, but may hinder animal performance through increased intramammary infection risk and gaseous emissions from the manure pack. This system may be acceptable for producers willing to intensively manage the system and absorb the additional bedding costs necessary to maintain a clean and dry resting surface for cows.

**COMPOST BEDDED PACK BARN**

Virginia dairy farmers developed the CBP barn concept to improve cow comfort, increase cow longevity, and reduce initial barn cost (Wagner, 2002). Using the BP system idea and incorporating composting methods, farmers conceived a housing design that could promote cow comfort, or the perceived environmental factors positively or negatively influencing the performance and health of a cow, while potentially reducing the mastitis risks associated with the BP. The CBP can meet the space, exercise, resting, and social needs of cows (Galama et al., 2011), making it a promising housing system to promote animal well-being. The composting process provides cows with a drier surface to lie on compared to the BP barn, but only with effective moisture management during composting.

**Composting Process**

Composting uses aerobic microbial digestion to decompose waste products, primarily consisting of manure and animal remains in agriculture, into rich, useable nutrients. Agricultural composting occurs as a waste management method in many livestock sectors. Broiler houses allow waste to accumulate under birds throughout the
bird growing process and then compost the waste after the chickens have been removed (Moore et al., 1995). Beef feedlot operations pile manure into rows and compost material further, producing a dry, odorless product (Eghball et al., 1997) with reduced volume and weight (Michel et al., 2004). Temperature, carbon to nitrogen ratio ($C:N$), aeration rate, pH level, moisture, and raw materials (manure, urine, animal remains, bedding, etc.) all impact the compost process (Ekinci et al., 2006, Liang et al., 2006, NRAES, 1992, Sundberg et al., 2004). The compost process relies on optimization of aeration, temperature, and moisture.

**Moisture.** Maximum nutrient transfer rate occurs in an aqueous environment of 100% moisture (Stentiford, 1996). However, the composting process cannot occur in a liquid environment because the composting material is solid. The composting process operates optimally between 40 and 60% moisture (Jeris and Regan, 1973, Stentiford, 1996, Suler and Finstein, 1977). A drier environment with a moisture content between 30 and 35% inhibits microbial activity (Stentiford, 1996). Excessively wet compost, typically above 60%, inhibits free air space and aeration ability (Schulze, 1961) because of greater susceptibility to compaction (Das and Keener, 1996). Though moisture is necessary for nutrient transfer, aeration is also important to maintain an aerobic environment for the microbial population.

**Aeration.** Aeration is the agitation of compost material providing air to the aerobic composting microorganisms. Lack of air creates an anaerobic environment, producing excess ammonia, methane, and hydrogen sulfide gases (Lopez-Benavides et al., 2007). Aeration rate depends on the starting material (wood, sawdust, newspaper, manure, poultry litter, etc.), temperature, compost stage, and compost conditions.
(moisture content, material structure)(Stentiford, 1996). An oxygen level ranging from 5 to 15% sustains high compost temperature by not limiting aerobic respiration (Epstein et al., 1978). An excessive aeration rate can have negative consequences developing air passages within the compost. Air passageways create fluctuating temperature and moisture profiles leading to a non-uniform end product (Das and Keener, 1996) and compost pile cooling, sustaining pathogen survival because some areas did not reach adequate sanitization temperatures (55 to 65 ºC)(Epstein et al., 1978). Depending on the composting system, multiple aeration methods can be used.

Windrow management involves a turning regimen using a compost windrow turner. Compost windrow turners are driven over the windrows slowly while steel paddles rapidly turn the compost material (Cobey, 1968). Temperature dictates the turning schedule: typically every three to four d in the first two to three weeks (wk) of composting and then weekly turnings until the compost temperature no longer increases (Stentiford, 1996). The main system disadvantage is the constant fluctuation in temperature surrounding the turning times, not allowing the compost to reach optimal degradation conditions for an appropriate time period (Pereira-Neto and Stentiford, 1986).

Forced aeration employs pressurized air systems to push air through the compost material. The disadvantage associated with this system is the manager’s inability to control the physical conditions within the compost material because of lack of mixing (Stentiford, 1996). Close attention should be paid to the oxygen amount supplied and the heating and cooling that occurs from that supply (Stentiford et al., 1985). A hybrid system of agitation and forced aeration helps to overcome the disadvantages of the two
previous systems by adequately supplying air to maintain the high temperature needed for sufficient biodegradation. Additionally, agitation ensures the mixture is uniformly degraded. This hybrid option requires a greater capital investment but speeds up the composting process and produces a uniform product (Stentiford, 1996).

**Temperature.** With proper aeration, microbes are able to degrade compost material producing metabolic heat, the composting heat source. Temperature is the best composting process efficiency indicator (Imbeah, 1998) and is the parameter that sets the biological process rate for degrading the compost material (Stentiford, 1996). Pathogen destruction, or sanitization, occurs when compost temperatures reach 55 to 65 °C; however, efficient compost material degradation occurs when temperatures are between 45 and 55 °C. Temperatures falling below 40 °C indicate minimal microbial activity and a slow composting rate. Therefore, monitoring temperature allows for a basic understanding of the amount and type of microbial activity occurring within the compost (Stentiford, 1996).

**Microbial Activity.** Temperature results from sufficient energy substrate that supports the active microbial population within the compost environment. Composting involves two microbe groups: mesophilic and thermophilic. Mesophilic microorganisms thrive in moderate temperatures (20 to 45 °C) and thermophilic microorganisms thrive in high temperature environments (50 to 70 °C)(Misra et al., 2003). The mesophilic composting stage lasts until mesophilic microbes die from a rapid increase in temperature, transitioning the compost to the thermophilic stage (Beffa et al., 1996). This stage is disrupted when the microorganisms exhaust the readily digestible substrate and the cooling phase begins (Beffa et al., 1996). Fully composted material is crucial for end
product field application because immature composts may regain microbial activity potentially causing oxygen and nutrient deficiency to the soil and toxicity problems in plant roots (Inbar et al., 1990, Zucconi et al., 1981).

**Barn Design**

Facility design can govern the success or failure of the composting process within a CBP barn. A number of design considerations are important when managing for efficient composting. Compost bedded pack barns provide an open resting area free of stalls or partitions, often surrounded by a 1.22 m wall to act as manure storage for at least six to 12 months (mo) (Janni et al., 2007). Figure 1.2 depicts a general CBP barn layout described by Janni et al. (2007). To compensate for the loss in sidewall height due to the retaining wall, eaves should be built at 4.9 m high instead of the typical 3.7 m height recommended for freestall barns (Janni et al., 2007). This increase in height improves natural ventilation and ensures feeding and CBP stirring equipment can access the barn when the CBP height increases (Janni et al., 2007). In a study by Barberg et al. (2007a) sidewall height ranged from 3.7 to 4.9 m, indicating some producers used recommendations for freestall facilities possibly restricting natural ventilation. Similarly, Damasceno (2012) observed 66.7% of barns (n = 47) with sidewall height between 2 and 4 m, less than the height recommended. To minimize the amount of rain and snow that enters the barn from the high sidewalls, overhang length should be a minimum of 1.52 m or one-third of the sidewall height (NRAES, 2006).

Site location and barn orientation affect the amount of natural ventilation a barn experiences and the amount of sunlight that penetrates the barn interior. Building barns on high ground and a minimum of 22.9 m away from other structures promotes natural
ventilation (Chastain, 2000). Additionally, designing barns with an east-west orientation reduces the amount of sunlight that shines directly onto cows (Smith et al., 2001). Sunlight travels from east to west increasing cow exposure to sunlight in a north-south oriented barn (Figure 1.3). Sun exposure is reduced when the barn is oriented east-west (Figure 1.4) because the barn roof is aligned with the sun’s path. Damasceno (2012) reported northeast-southwest and northwest-southeast orientations as the most frequently CBP barn orientations in Kentucky.

The ridge vent affects ventilation and the environment in the barn by removing warm, moist air under the barn roof. The primary types of ridge vent openings include: open, open with an interior gutter, open with upstands, open with a cap, open with a cap and upstands, overshot, and overshot with upstands (NRAES, 2006). Overshot designs are not recommended because they are not suitable for multiple wind directions. The opening is successful at heat dissipation when the wind blows over the overshot roof, but is unsuccessful when the wind blows into the overshot roof. The open ridge design is compatible with multiple wind directions because no barrier exists to block the wind. This design allows for optimal heat and moisture dissipation, however, producers are reluctant to adopt this design due to reservations about rain and snow coming into the barn. When enough cows are housed in the barn, enough heat should be produced to create a chimney effect to push hot air out of the ridge vent and weather should not enter the barn. Still, for producers with reservations about the open ridge design, the capped ridge design is an appropriate compromise. The cap blocks rain from dropping directly into the barn while still allowing wind to push heat and moisture from the barn from any direction. Producers may still notice some weather blowing into the barn when extreme
wind is associated, but the amount is likely reduced. Graves and Brugger (1995) recommend the open ridge design without a cap because the caps are expensive and will reduce airflow if improperly designed and installed. Recommendations should also be followed regarding the ridge vent dimensions (NRAES, 2006), with 5.1 cm of ridge vent opening for every 3.1 m of barn width. Compost bedded pack barns in Kentucky were typically built with the overshot ridge design (59%), and some barns were constructed with an open ridge with a cover (19%), open ridge with a cap (12%), or open ridge (5%)(Damasceno, 2012). Hoop structures constituted 5% of barns visited. Barberg et al. (2007a) noted that five of the 12 barns in the study did not have ridge vents with the appropriate width for optimal heat dissipation.

Feed alley width recommendations are greater than that of a freestall barn, recommending 3.6 to 4.3 m, because the waterer is in the feed alley (Bewley and Taraba, 2009). Alley widths allow cows to stand parallel at the feed bunk and stand at the waterer while still allowing cows to pass through to prevent cow flow problems. Compost bedded pack entrances at each end of the feed alley, or every 35 to 40 m for large CBP barns, provide convenient access to for cows and equipment (Janni et al., 2007). Feedbunks should allow adequate space per cow of 0.03 to 0.06 m/cow to encourage all cows to eat (Smith et al., 2001); however, Damasceno (2012) observed 25% of barns with inadequate feedbunk space per cow. Forty-four percent of the barns did not have direct access to the feedbunk from the CBP (cows were required to travel to the feedbunk) and 53.2% of barns only had feedbunk access on one side of the CBP. Feedbunk length requirement is greater when access is only permitted on one side of the barn, requiring barns to be longer to meet that requirement. As with space at the
feedbunk, waterer space and location is important for health and dry matter intake. Waterers should be placed in a convenient location adjacent to the feedbunk with access only on the feed alley (Janni et al., 2007). Damasceno (2012) reported that only 19% of farms supplied adequate waterer space of 3.0 to 4.1 cm waterer perimeter space per cow and 24% of barns had no waterer access from within the barn, possibly reducing overall water intake. Water access is necessary inside the barn; however, allowing waterer access from within the CBP creates excessively wet areas because cow traffic increases and cows may push water out of the waterer onto the CBP. Excess water disrupts the composting process, and waterer height must be adjusted as the CBP height increases or after barn cleanout (Janni et al., 2007).

Several producers and researchers around the world have embraced the CBP concept and created new designs to best suit climatic conditions. Galama et al. (2011) reported multiple housing plans for producers in The Netherlands including a conventional CBP with a drive through feeding system, automated feeding system, high degree of automation, and mobile feed mangers. Israeli producers developed a similar CBP barn concept; however, in some barn designs, the feed manger resides next to the CBP instead of beside a concrete feed alley. Feed alley removal allows manure and urine produced while feeding to be deposited onto the CBP (Klaas et al., 2010).

Building a barn with the correct design that maximizes natural ventilation promotes an active composting environment. However, the CBP system requires a proactive management style to work effectively and building a barn with dimensions that would allow easy conversion to a freestall barn might be a practical choice for some producers (Janni et al., 2007, Wagner, 2002).
Pack Management

To obtain an effective composting system, proper facility design and intensive management are necessary. The system is living and must be constantly monitored and observed to maintain a healthy, viable composting environment. Similar to traditional composting, producers must manage the CBP for aeration, temperature, and moisture to achieve successful composting.

Temperature. Similar to the conventional composting process, temperature is a key measure of composting efficiency and improved through active compost material aeration to support microbial heat production. One composting system advantage is the CBP volume reduction (Michel et al., 2004). Temperatures between 40 and 50 °C achieve the greatest cellulose degradation (Fergus, 1964, Jeris and Regan, 1973, Kuter et al., 1985), potentially leading to greater CBP height reduction and increased manure storage length. Barberg et al. (2007a) reported a mean CBP temperature of 42.5 °C across 12 barns studied and noted that temperatures were not significantly different across different depths in the CBP. Klaas et al. (2010) studied three CBP barns in Israel not using an additional bedding source for moisture absorption. One CBP barn observed a CBP temperature range between 25 and 42 °C, an increase ranging from 7 to 24 °C above ambient temperature. However, temperatures did not increase above ambient temperature in two additional barns sampled managed in a similar manner.

Higher temperatures promote pathogen destruction (Stentiford, 1996) which may be advantageous for mastitis-causing bacteria destruction. However, temperatures observed by Barberg et al. (2007a) and Klaas et al. (2010) did not reach the level necessary (55 to 65 °C) for sanitization. Temperature ranges for pathogen destruction (55
to 65 °C) and pack volume reduction (40 to 50 °C) differ, indicating a management decision is required to manage for increased manure storage time by reducing pack volume or pathogen destruction by increased composting temperatures. However, the CBP system may not allow for temperature ranges promoting pathogen destruction because frequent aeration cools the pack (Epstein et al., 1978).

**Aeration.** Typically, a cultivator or rototiller incorporates air into the pack during milking time, two or three times per d (Barberg et al., 2007a, Janni et al., 2007, Shane et al., 2010). Both the cultivator and rototiller have advantages and disadvantages. Using a field cultivator may allow for deep stirring (25.4 to 45.7 cm) and promotes a deeper active composting layer by aerating more material. However, the rototiller, though not stirring as deep (10.2 to 15.2 cm), breaks material down more finely which brings air to more compacted material and opens more surface area for microbes to digest. Aeration frequency is important in maintaining an oxygen level between 5 and 15% (Epstein et al., 1978). Cows compact the CBP when walking and lying on the CBP and reduce the amount of free air space (Kader et al., 2007). Frequent stirring, two to three times daily, creates a “fluffy” compost surface layer needed to allow air flow into the composting material and increase pack drying (Janni et al., 2007). Researchers hypothesized that compaction reduces airflow and microbial activity. However, stirring the CBP increases airflow and compost material exposure to air, increasing CBP moisture evaporation.

Janni et al. (2007) recommended stirring the CBP 25 to 30 cm deep. A field survey by Barberg et al. (2007a) reported that producers only stirred 18 to 24 cm deep. Not stirring deep enough has several consequences. First, shallow stirring creates a larger depth of anaerobic conditions as the CBP height increases (Russelle et al., 2009).
Second, creating a more shallow active layer reduces the layer’s ability to maintain high
temperature due to the proximity to the atmosphere where evaporative cooling may
quickly reduce CBP temperature (Galama et al., 2011). Lastly, the reduced temperatures
may not allow proper drying. A wetter environment is less hygienic for cows and
increases exposure to environmental mastitic pathogens.

The CBP fermentative layer that occurs once the cultivator or rototiller can no
longer stir the entire CBP depth is a management concern. Fermentation can have
negative consequences to air quality through the production of methane, organic acids,
and hydrogen sulfide (Misra et al., 2003). Oxygen concentrations less than 5% indicate
an anaerobic environment (Epstein et al., 1978, Fernandes and Sartaj, 1997, NRAES,
1992, Schulze, 1962). Kapuinen (2001a) suggested the need for forced bottom layer
aeration to maintain active biodegradation throughout the CBP, postulating that aerating
these layers might shorten the composting process and prevent anaerobic conditions. In
addition, this management practice could potentially continue to reduce the CBP size and
increase the time between barn cleanouts.

Moisture. Higher temperatures, promoted by aeration, increase moisture
evaporation (NRAES, 1992), indicating an interaction between moisture and temperature,
and the importance to manage both parameters simultaneously. The combination of
manure and substrate should not exceed a moisture content of 70% (Gray et al., 1971a,
Schulze, 1962), though a range of 50 to 60% is preferred (Gray et al., 1971b, NRAES,
1992, Suler and Finstein, 1977). Manure, urine, and microbial activity moisture act as
moisture sources for a CBP (Janni et al., 2007). Barberg et al. (2007a) observed that the
lower 15 to 30 cm CBP depth contained a higher moisture content of 56.7% compared to
the top 15 cm depth with a moisture content of 50.7%. Overall, the mean moisture content across the 12 barns sampled was 54.4%. Russelle et al. (2009) observed higher moisture levels of 61% in the fluffy, composting layer and 64% in the compact, fermentative layers for CBP barns sampled.

During the cooler portion of the year, the top layer only allows a fraction of deposited moisture to evaporate, requiring excess moisture to either drain to lower layers, be absorbed by additional bedding material, or evaporate using additional airflow (Galama et al., 2011). However, additional airflow may cause draft concerns for the cows. A relevant solution is to increase space per cow when increased air speeds are not a plausible solution (Galama et al., 2011).

**Cow Density.** Optimal cow stocking density is dependent on the amount of manure and urine deposited into the pack, allowing microbial activity to be active and surface drying to be balanced with moisture deposited (Janni et al., 2007). More moisture deposited requires more space per cow, more bedding to absorb the moisture, or increased aeration to provide more air and evaporation. However, a minimum amount of space per cow must allow all cows to lie down at the same time while still allowing space for cows to travel to the feedbunk or waterer (Janni et al., 2007). Assuming an average Holstein cow, a lying space of 259.1 cm long and 132.1 cm wide is required (Anderson, 2009), resulting in a minimum lying space of 3.4 m²/cow. Additional space for standing requires 50.8 cm of lunge space, meaning each cow needs 4.1 m² of living space. Wagner (2002) originally recommended 9.4 m²/cow for Virginia CBP barns. However, based on a cow’s manure and urine output, Janni et al. (2007) recommended 7.4 m²/cow for a 540 kg cow or 6.0 m²/cow for a 410 kg Jersey cow for Minnesota CBP barns.
Barberg et al. (2007a, 2007b) observed a mean of 8.6 m²/cow in CBP barns in Minnesota, less than that recommended by Wagner (2002) but greater than the recommendation by Janni et al. (2007). Compost bedded pack barns managed in Israel where no added bedding is used require greater space per cow to account for the reduced water holding capacity, recommending a minimum of 15 m²/cow when cows feed off a concrete feed alley and between 20 and 30 m²/cow when cows feed off the CBP (Klaas et al., 2010). Similarly, CBP barns in The Netherlands offer 15 m²/cow to reduce moisture input and bedding requirements (Galama et al., 2011).

**Barn Cleanout/Manure Storage.** The CBP acts as both resting area floor and manure storage. The time between barn cleanout is dependent on stocking density, bedding use, height of the retaining wall, and composting efficiency but typically occurs once or twice per y (Barberg et al., 2007a, Barberg et al., 2007b, Shane et al., 2010). Cleaning out the barn in early fall enables the CBP to generate sufficient microbial activity and heat before cold weather begins (Janni et al., 2007). A manure lagoon or stack pad collects manure and urine excreted in the feed alley, holding pen, parlor, and walkways requiring two types of manure handling equipment (Janni et al., 2007), one for liquid manure in the lagoon, and one for solid material in the CBP. An Israeli study by Klaas et al. (2010) reported producers redistributing the scraped manure from alleyways, the parlor, and holding pen back onto the CBP, or eliminating the alleyways and allowing the CBP to extend to the feed bunk. Janni et al. (2007) did not recommend the practice of redistributing the manure onto the CBP because it would increase bedding requirements related to additional moisture. Additionally, the practice of evenly distributing the manure onto the CBP may be difficult and could create areas of higher or lower moisture.
throughout the CBP. Janni et al. (2007) recommend using alternative manure storage to collect the manure from the alleyways and holding pen.

**Bedding.** Bedding management is crucial to operating a successful CBP barn and increasing the time between barn cleanouts. Producers use wood shavings or sawdust, typically finely processed, which improve mixing and aeration along with microbial activity because of increased surface area compared with straw and woodchips (Janni et al., 2007). Furthermore, Kapuinen (2001a) determined wood chips do not improve the composting process due to the small surface area to volume ratio. Janni et al. (2007) hypothesized that wood shavings or sawdust were the optimal bedding material because of the lignin content, large surface area to volume ratio, and compaction is limited between CBP stirring. Lignocellulosic materials are resistant to microbial degradation (Whitney and Lynch, 1996) and contribute to lasting compost material structure. Cow density, ambient weather conditions, airflow, and cow hygiene dictated new bedding addition frequency (Barberg et al., 2007a, Janni et al., 2007). Barberg et al. (2007a) described that producers typically added 30 to 45 cm of new bedding to begin a CBP and subsequently add new bedding every two to five weeks.

Janni et al. (2007) recommended avoiding green or wet sawdust or shavings because of possible increased teat end exposure to *Klebsiella* bacteria, a cause of environmental mastitis. Fairchild et al. (1982) reported increased *Klebsiella* levels in fresh sawdust bedding samples compared to the same used sawdust bedding samples (Wk 1: $2.8 \times 10^4$ cfu/g; Wk 9: $0.6 \times 10^4$ cfu/g). However, these differences were not significant ($P > 0.05$). *Klebsiella* species survive in hardwood and sapwood (Bagley et al., 1978) and not heating the wood used for bedding may increase udder exposure to
these pathogens. Newman and Kowalski (1973) reported 3 of 4 sawdust samples and 29 of 54 milk samples contained *Klebsiella* species. However, only a few cows exhibited any clinical or subclinical mastitis signs. *Klebsiella* species fecal shedding may also create conditions conducive to increased mastitis incidence. In a study by Munoz et al. (2006), 80% of 100 cows sampled tested positive for *K. pneumoniae*. Furthermore, Verbist et al. (2011) determined contamination of bedding to be mostly from fecal shedding of *K. pneumoniae*. Unused bedding acted as an unimportant source of *K. pneumoniae*. Green sawdust may increase exposure to *Klebsiella* species, but other environmental sources may also contribute to mastitis incidence caused by *Klebsiella* species. Using kiln-dried shavings, finding an alternative bedding source, or maintaining a clean, dry resting environment may reduce exposure to *Klebsiella* species.

**Alternative Bedding Sources.** With high sawdust bedding costs and a supply shortage, interest in alternative bedding sources arose in Minnesota (Shane et al., 2010). A Minnesota study by Shane et al. (2010) investigated alternative bedding source viability for six CBP barns. Barn A used different bedding materials throughout the study including sawdust, wood chips, flax seed, and wheat straw. Summer CBP temperature was 33.3 °C and ambient temperature ranged from 14.8 to 26.8 °C. Compost bedded pack depth was too shallow to collect temperatures during the spring, summer, and fall. Barn B used a mixture of 90% sawdust and 10% oat hulls for bedding material. Compost bedded pack temperature was consistently higher in winter, summer, and fall (7.7, 35.2, and 27.0 °C, respectively) compared to the maximum ambient temperature during winter, summer, and fall (-2.3, 26.8, and 20.6 °C, respectively). Compost bedded pack depth was too shallow to collect temperatures in the spring. Barn C used a fine
wheat straw material for bedding and observed higher CBP temperatures in winter, spring, summer, and fall (28.1, 39.4, 48.1, and 40.9 °C, respectively) compared to the maximum ambient temperature in winter, spring, summer, and fall (-3.4, 16.5, 26.6, and 18.2 °C, respectively). Barn D used a mixture of sawdust and soybean straw in winter and spring, sawdust in part of the summer, and no bedding in summer and fall. Compost bedded pack temperatures were higher in winter, spring, summer, and fall (40.6, 38.3, 40.1, and 31.0 °C) compared to the maximum ambient temperature in winter, spring, summer, and fall (-4.0, 15.8, 26.8, and 16.8 °C). Barn E used chopped wheat straw in winter, spring, and summer, and a mixture of soybean straw, wheat straw, sawdust, and wheat sawdust in fall. Compost bedded pack temperatures were higher in winter, spring, summer, and fall (13.8, 20.8, 32.8, and 42.2 °C, respectively) than the maximum ambient temperature in winter, spring, summer, and fall (-5.1, 15.8, 27.3, and 22.7 °C, respectively). Barn F used soybean stubble in the winter as bedding material and sawdust in the spring, summer, and fall. Compost bedded pack temperatures were higher in the winter, spring, summer, and fall (17.6, 25.5, 31.8, and 32.8 °C, respectively) compared to the maximum ambient temperature in the winter, spring, summer, and fall (-4.3, 16.0, 26.4, and 21.6 °C, respectively). Researchers concluded that all the materials could support microbial activity, attributable to the increase over ambient temperature, and increased the CBP temperature, which was comparable to sawdust.

A second Minnesota study by Shane et al. (2010) examined differences in bedding materials including sawdust (SD), corncobs (CC), soybean straw (SS), pine woodchip fines mixed with SD (WC/SD), SS mixed with SD (SS/SD), and WC mixed with SS (WC/SS). Corncobs and SS cost the most per cow per d and SD cost the least.
(CC: $1.90/cow/d; SS: $1.45/cow/d; SS/SD: $0.85/cow/d; WC/SS: $0.60/cow/d; WC/SD: $0.45/cow/d; and SD: $0.35/cow/d). Corncobs produced higher CBP temperatures than all other materials ($P < 0.001$), with SD producing the next highest CBP temperatures ($P < 0.01$)(CC: 39.8 ºC; SD: 30.6 ºC; SS/SD: 26.3 ºC; WC/SD: 22.6 ºC; WC/SS: 19.8 ºC; SS: 12.7 ºC). Similarly, corncobs resulted in reduced moisture compared to the other materials ($P < 0.001$)(CC: 44.5%; SD: 59.7; SS/SD: 58.2; WC/SD: 60.6; WC/SS: 60.7; SS: 60.6).

Kapuinen (2001a) studied alternative bedding sources in deep litter systems for beef cattle including peat, straw, and wood chips. A straw and peat mixture, with peat not exceeding 60% of the mixture, proved to act as a sufficient litter mix for composting based on high temperatures and mass loss. Van Dorren et al. (2010) examined organic and inorganic alternative bedding sources and discovered that inorganic materials and compacted bedding produce increased ammonia emissions. Rubber shavings as bedding produced the lowest ammonia emissions of the inorganic beddings sampled and dewatered peat dredge resulted in the lowest ammonia emissions for the organic bedding categories. Another concept practiced in Israel employs the notion of no additional bedding sources, using only manure as a composting substrate (Klaas et al., 2010). Researchers examined CBP barns using an assortment of starting materials including residual paper products, inorganic residuals from oil extraction, and dried manure. The farm starting the CBP with dried manure observed CBP temperatures between 25 and 42 ºC, temperature increases ranging from 7 to 24 ºC above ambient temperature. The other farms observed no rise in temperature over ambient. Therefore, manure was the only substrate that could generate an active composting environment.
Manure Value. Compost bedded pack nutritive value is of particular importance because the product may ultimately end up on a field as fertilizer. Nitrogen is typically the limiting factor in the composting process due to the carbon source abundance from bedding (Whitney and Lynch, 1996); however, the continual addition of manure may supply the necessary nitrogen. A C:N between 25 and 35 is recommended for an optimal compromise between efficient composting and around 30% nitrogen loss (Gray et al., 1971b, Kirchmann, 1985, NRAES, 1992). In a high C:N environment, nitrogen is limiting and reduces the composting rate. This may occur when too much bedding exists in the composting environment. However, a low C:N implies a nitrogen content which is too high, leading to increased ammonia emissions (Kapuinen, 2001b, Li et al., 2008). This may occur when bedding addition is limited.

Barberg et al. (2007a) observed a total CBP nitrogen content of 2.54%, phosphorus content of 0.32%, potassium content of 1.53%, and C:N of 19.5:1. They noted that the values closely compared to those expected in lactating dairy cow manure. Russelle et al. (2007) observed similar nutritive values with a total CBP nitrogen content of 1.09%, phosphate content of 0.28%, potash content of 0.74% in the surface layer and 0.67% in the deep compacted layer, and a C:N ranging from 11.2:1 to 20.9:1. A study of alternative bedding sources (Shane et al., 2010) reported CBP C:N values ranging from 16.0:1 to 26.0:1 in the winter and 15.3:1 to 18.2:1 in the winter. All C:N values were below that recommended for efficient composting. Additionally, phosphorus ranged from 0.28 to 0.43% in summer and from 0.15 to 0.26% in winter, and potassium ranged from 0.78 to 1.92% in summer and from 1.42 to 2.27% in winter. Compost pH can have an impact on composting efficacy by affecting the growth response of organisms.
Composting is most efficient when pH is between 6.5 and 8.0 (NRAES, 1992). Ammonia emissions increase when compost material pH exceeds the optimum and exposed to air, which is particularly important during barn cleanout (Russelle et al., 2007). Barberg et al. (2007a) observed a CBP pH between 8.4 and 8.6, which is greater than the recommended range of 6.5 to 8.0 (NRAES, 1992), possibly leading to ammonia release concerns.

Sampling the CBP before field application is recommended (Russelle et al., 2009). Russelle et al. (2009) remarked that no apparent spatial pattern in nutrient content existed, which allows for random CBP sampling for nutritive value. However, researchers did recommend a composite sample of 10 locations throughout the pack when determining nutritious value. Additionally, CBP sampled contained similar densities in the upper stirred layer and the lower fermentative layer, implying the ability to estimate total CBP volume available to apply to the field.

**Environmental Conditions.** Compost efficiency affects both compost nutrient value and emissions. Materials, which are well composted, resulted in reduced odor emissions (Janni et al., 2007) because anaerobic odor products, such as hydrogen sulfide, volatile fatty acids, and aromatic compounds, were not produced. Lobeck et al. (2012) evaluated the environmental conditions of three different dairy housing facilities. They observed a greater ($P < 0.05$) ammonia concentration in the cross-ventilated (CV) barn (5.2 ppm) compared to the CBP barn (3.9 ppm) and naturally ventilated (NV) barn (3.3 ppm). The CV barn also contained greater ($P < 0.05$) hydrogen sulfide concentrations (32 ppb) than the CBP barn (13 ppb) and NV barn (17 ppb). Shane et al. (2010) identified similar values of 3.9 ppm for ammonia concentration and 23 ppb for hydrogen
sulfide concentration in the CBP barn. These results compare to those observed by Klaas et al. (2010) who noted that CBP area had ten times lower ammonia emissions than in the feed alley, an environment analogous to a freestall barn. Barberg et al. (2007a) further described ammonia emissions to be higher in the lower, compact layer (14 to 28 cm deep, 857 ppm) compared to the surface, fluffy layer (6 to 14 cm deep, 461 ppm), possibly due to aeration.

Lobeck et al. (2012) described the temperature humidity index (THI) for the three different housing systems. In summer, the CV reduced THI by 0.5 compared to ambient conditions (THI = 66.4), but the CBP and NV barns experienced elevated THI (67.7 and 68.2, respectively) compared to ambient conditions (65.7 and 65.8, respectively). These results suggest that the CBP environment may increase heat load on cows in summer due to the microbial heat produced. Therefore, appropriate heat abatement strategies are imperative.

**Bacterial Counts**

Environmental conditions may affect bacterial populations in CBP barns. The summer season promoted greater *Bacillus* species concentrations at the CBP surface than the winter season (Lobeck et al., 2012; *P* < 0.05). Shane et al. (2010) detected higher *Staphylococcus aureus* and coliforms levels in the bulk tank milk in summer than winter, but detected no *Streptococcus agalactiae* in summer or winter. A Minnesota study by Barberg et al. (2007a) reported a total bacterial count of 9,122,700 cfu/mL in 12 CBP barns at the surface layer. A bacterial content of greater than 1,000,000 cfu/mL was expected to be a risk for clinical mastitis (Jasper, 1980). Bacterial contributions consisted of 10.7% coliforms, 39.4% environmental *Streptococcus*, 17.4% environmental...
*Staphylococcus*, and 32.5% *Bacillus*. Lobeck et al. (2012) determined that CBP, CV, and NV barns exhibited no difference (*P > 0.05*) in coliform, *Klebsiella*, environmental *Streptococcus*, or *Staphylococcus* species in bedding samples during summer and winter and *Bacillus* species in bedding samples during summer. However, CBP barns contained lower (*P < 0.05*) *Bacillus* levels (800 cfu/mL) in the winter than NV barns (9,881,000 cfu/mL). Bulk tank milk contained similar *Staphylococcus aureus*, non-ag *Streptococcus*, *Staphylococcus* species, and coliform levels for the three housing systems. A direct correlation exists between the bacteria load at the teat end and mastitis incidence (Neave et al., 1966) making it imperative to manage teat end cleanliness. Bedding contributes to teat end bacterial load (Hogan and Smith, 1997, Hogan et al., 1989, Zdanowicz et al., 2004) and minimizing bacterial counts in bedding is an important management strategy for minimizing mastitis incidence.

**Lying Behavior**

Lying behavior is often considered an animal welfare indicator and is used as a objective cow comfort comparison between housing systems (Fregonesi and Leaver, 2001, 2002, Haley et al., 2001, Ketelaar-de Lauwere et al., 1999, Metz, 1985, Singh et al., 1993). Housing systems and management affect lying times, perhaps associated with cow comfort on softer lying surfaces (Krohn and Munksgaard, 1993). Cows exhibit a strong desire to lie down and, if deprived of lying, lying motivation can supersede that of other activities including feeding (Metz, 1985, Norring et al., 2012) and cause abnormal behavior (Ruckebusch, 1974).

Cook et al. (2004), reported lying times of 11.7 and 12.0 h/d (*P > 0.05*) in mattress base and sand based freestalls, respectively, similar to that reported by Ito et al.
(2009) of 11.0 h/d in freestall herds. Drissler et al. (2005) examined lying times with different sand levels in freestalls and determined cows spent more time lying down when stalls were more full (sand level with curb: 13.7 h/d; sand 13.7 cm below curb height: 11.4 h/d; $P < 0.01$). High producing cows, housed in freestall barns with reduced space allowance, laid down for less time (9.5 h/d) compared to high producing cows with high space allowance (10.4 h/d) and low producing cows with high and low space allowance (10.5 and 10.5 h/d, respectively)(Fregonesi and Leaver, 2002); however, these differences were not significant. Conversely, when cows were housed in BP barns, lying time ranged from 10 to 14 h/d (Fregonesi and Leaver, 2002, Singh et al., 1993).

Eckelkamp et al. (2013) reported that cows transitioning from an outdated freestall barn to a CBP barn spent 4 h/d more lying in the new CPB than in the outdated freestall system (13.1 vs. 9.1 h/d, respectively). Further, lame cows (locomotion score $\geq 3$ using scoring system by Sprecher et al. (1997) spent 5 h/d more lying on the CBP compared to the freestall system (13.1 vs. 8.0 h/d, respectively, $P < 0.05$). Sound cows (locomotion score $\leq 2$) increased lying time by 3.0 h/d when transitioned from the freestall system to the CBP barn (10.1 vs. 13.1 h/d respectively, $P < 0.05$). Endres and Barberg (2007) reported a lying time of 9.3 h/d for cows housed on a CBP barn. Additionally, cows without access to pasture lay down more than cows with pasture access (9.99 h/d vs. 6.45 h/d, respectively). Lying times reported are less than those reported by Eckelkamp et al. (2013), possibly because cows in the latter study were transitioning from an outdated freestall barn to a new CBP, allocating more time to lying than other activities for recuperation.
Researchers observed similar lying bouts between housing systems; 10.3 bouts/d in a straw yard (Singh et al., 1994), 10.3 bouts/d (Cook et al., 2004) and 11.4 bouts/d (Drissler et al., 2005) in a deep-bedded sand freestall (SF) barn, and 11.5 bouts/d in a mattress freestall (MF) barn (Cook et al., 2004). Cow lying bouts when housed in a CBP barn averaged 11 bouts/d (Endres and Barberg, 2007) and 17.3 bouts/d (Eckelkamp et al., 2013). Livshin et al. (2005) reported cows housed in a freestall system laid down 20% less than those in a BP barn. Haley et al. (2001) reported that cows on softer lying surfaces lay down for a longer total time than cows housed on concrete, however, the total lying bout length is shorter. Researchers hypothesized that the increased bout length of cows housed on concrete is due to the discomfort of rising and lying when resting on concrete.

Cows perform four different resting positions (Krohn and Munksgaard, 1993): flat on side (cow lies flat on one side with her head stretched out and resting on the ground), head back (cow is lying on chest with head resting on body towards hindquarters), head on ground (cow is lying on chest with head stretched out on ground in front of chest), and head up (cow is lying on chest with head elevated). Endres and Barberg (2007) observed most cows in a CBP barn lying in the head up position (84.6%), while 8.8% assumed the head back position, 5.4% exhibited the head on ground position, and 0.8% laid flat on their side. Krohn and Munksgaard (1993) reported cows on pasture spending more total time lying flat on their side (1.6%) and with their head on the ground (6.7%) compared to a BP barn (0.7 and 2.6%, respectively), tie-stall barn with straw bedding (TS) (0.7 and 2.5%, respectively), tie-stall barn with a mattress base (TM) (0.6 and 3.0%, respectively), and tie-stall barn with a mattress base and exercise allowance (TME) (0.6 and 2.6%,
respectively)\((P < 0.05)\). They also reported more time spent lying down from initial examination of the ground (cow standing searching for area to lay down) until fully lying in tie stall barns (TS: 149 s; TM: 123 s; TME: 118 s) compared to the BP barn (59 s) and pasture (19 s)\((P < 0.05)\). Haley et al. (2000) observed head positions of cows housed in freestall and tie-stall barns, reporting similar percentage of daily observations with the head against the body (freestall: 5.3%; tie-stall: 4.8%) and on the ground (freestall: 0.7%; tie-stall: 1.9%). However, they reported increased percentage of daily observations of cows in freestalls with their heads up while lying (54.7%) compared to tie-stall housed cows (37.4%).

**Animal Health**

*Lameness.* Animal health and well-being attracts consumer attention everywhere (Verbeke and Viaene, 2000). Dairy cow lameness is of particular interest due to its continual spotlight in the media (Archer et al., 2010). Therefore, lameness is an important welfare concern for producers to ensure optimal animal health and well-being (Whay et al., 2003) to satisfy cow needs and public concerns.

Economic losses experienced from lameness can occur from decreased milk production, reproductive performance, and longevity (Cha et al., 2010). Cha et al. (2010) calculated an average cost of $177.62 per case of lameness, considering sole ulcers, digital dermatitis, and foot rot, taking into account milk loss, decreased fertility, and treatment cost. Green et al. (2002) reported a 1.2 kg/d reduction in milk production due to lameness and Warnick et al. (2001) observed a 2.6 kg/d decrease in milk production for lame cows. Days to conception increased for lame cows with claw lesions and multiple lesions compared to sound cows (140, 170, and 100 d, respectively). Lame
cows with claw lesions also required 5 breedings per conception compared to 3 breedings for sound cows (Hernandez et al., 2001). Melendez et al. (2003) determined that, compared to sound cows, lame cows exhibited lower conception rate at first service (42.6 vs. 17.5%, respectively, $P < 0.05$) and higher ovarian cyst incidence (11.1 vs. 25%, respectively, $P < 0.05$). A study conducted by Booth et al. (2004) indicated that lameness either increased the risk for culling or did not alter the risk but never reduced the risk for culling. Researchers hypothesized that lameness cause, diagnosis time, and d in milk influenced the culling risk. Sprecher et al. (1997) reported that lame cows were 8.4 times more likely to be culled from the herd than sound cows.

Extreme lameness cases are the product of severe foot soreness caused by a number of hoof diseases including digital dermatitis, white line disease, heel erosion, foot rot, sole ulcers, and laminitis (Cook and Nordlund, 2009). Hoof diseases can be associated with nutrition, hormonal changes at time of calving, trauma to the hoof, housing design, management, and infectious agents that the hoof may be exposed to in the environment (Clarkson et al., 1993, Cook and Nordlund, 2009). Infectious disorders are influenced primarily by the environment (Manske et al., 2002).

Concrete can also contribute to foot soreness. Solid concrete in alleyways increased the risk for corkscrewed claws, heel horn erosions and white line hemorrhages and slatted concrete alleyways increased risk for white line fissures (Sogstad et al., 2005). Several studies have shown reduced lameness of cows housed in straw yards compared with slatted or concrete flooring (Hughes et al., 1997, Maton, 1987, Murphy et al., 1987, Phillips and Schofield, 1994, Somers et al., 2003, Vaarst et al., 1998) and pasture compared to slatted or concrete flooring (Faye and Lescourret, 1989).
Freestalls with incorrect stall dimensions deter cows from adequately using the stalls and increase lameness incidence. Stall hardware creates a compromise between cow comfort and cow cleanliness by creating barriers, which properly position cows to urinate and defecate in alleyways. Stalls with dimensions that account for cow size provide a resting space for cows to lie comfortably. Stalls wide enough should not contact cows during rising or lying motions and should not allow the cow to turn around and lie backwards in the stall. Stalls should be long enough to fit the length of the cow but short enough that feces and urine are excreted in the alley and not in the back of the stall (MWPS, 2000). The National Resource, Agriculture, and Engineering Service (2006) described the proper stall dimensions based on cow size. For herds with multiple breeds or cows of different frame sizes, stalls should be built for the largest cow in the herd (McFarland, 2003). Sogstad et al. (2005) showed an increased lameness risk when stalls are too narrow and an increased sole hemorrhage risk when stalls are too short. Cows provided stalls with no neck rails stood with all four hooves in the stall more than 3 times longer than cows provided stalls with neck rails at 102 cm high (83 vs. 22 min/d, \( P < 0.01 \))(Tucker et al., 2005). When provided stalls with a distance from the curb of 223 cm versus 140 cm, cows stood with all four hooves in the stall nearly eight times longer in lengthier stalls (86 vs. 11 min/d, respectively, \( P < 0.001 \))(Tucker et al., 2005).

Several studies have documented lameness incidence in freestall herds. Cook (2003) discovered lower mean lameness prevalence (locomotion scale of 1 to 4, where 1 is sound and 4 is severely lame; prevalence calculated as percent cows scored with locomotion score \( \geq 3 \)) among herds in SF (summer prevalence: 16.5%; winter prevalence: 18.9%) compared to herds in non-SF (summer prevalence: 24.4%; winter
prevalence: 26.9%). Similarly, MF demonstrated higher lameness prevalence than SF (24.0 vs. 11.1%) in another study conducted by Cook (2004). High producing cows (defined by herd manager; 37.6 ± 6.9 kg 3.5% FCM yield/cow per d) are more prone to lameness (lameness diagnosed by producer; Green et al., 2002) due to exposure to high stress from milk production, which can create adverse hoof health issues (Espejo et al., 2006). A survey of high producing Holstein cows in Minnesota determined a mean lameness prevalence (locomotion scale of 1 to 5, where 1 is sound and 5 is severely lame; prevalence calculated as percent cows scored with locomotion score ≥ 3) of 24.6% for both SF and MF housed cows, where cows housed in SF barns presented lower lameness prevalence than those in MF (17.1 vs. 27.9%) (Espejo et al., 2006). The increase in traction and cushion that sand offers may be an explanation of the improved hoof health of cows housed in SF barns compared to MF barns (Vokey et al., 2001).

Compost bedded pack barns avoid many issues causing lameness observed in freestall barns. The pack is free of concrete alleys between stalls and cows walk and stand on compost (Barberg et al., 2007a, Janni et al., 2007). Cook (2008) noted that cows spend an average of 14 h in the pen area (areas excluding feed alley, holding pen, and milking parlor) after eating, drinking, and milking times are accounted for. Therefore, when standing during those 14 h, cows are standing on a softer surface. Lobeck et al. (2011) conducted a study of animal welfare in CBP, CV freestall, and NV freestall barns discovering lower lameness incidence in CBP barns (4.4%) compared with the CV (13.1%) and NV (15.9%) barns. Earlier, Barberg et al. (2007b) observed higher results for CBP housed cows, where 7.8% of cows housed on the CBP exhibited clinical lameness. Researchers hypothesized that this prevalence may be associated with
previous injuries from prior housing. Producers participating in the study indicated that cows stayed in the herd longer due to improved rising and lying ease on the CBP. Shane et al. (2010) investigated alternative bedding materials for CBP barns and observed a seasonal difference where lameness prevalence was 9.1% in the fall, 12.1% in the spring, 12.2% in the summer, and 13.0% in the winter. On average, lame cows (score > 2) constituted 9.1% of the herd and severely lame cows (score > 3) made up 2.5% of the herd.

Barberg et al. (2007b) scored cows on a CBP with a mean body condition score (BCS) of 3.04 (where 1 = thin and 5 = obese, Ferguson et al., 1994), similar to the mean score of 3.03 observed by Shane et al. (2010) and the mean score of 2.91 observed by Lobeck et al. (2011). Culling rate decreased after moving into a CBP barn from 25.4% to 20.9% (Barberg et al., 2007b). Additionally, Lobeck et al. (2011) reported a culling rate of 30.1% for cows in Minnesota housed in a CBP barn.

Shane et al. (2010) reported 10.5% of cows observed on a CBP barn with a mild hock lesion and 3.8% with a severe hock lesion. The researchers hypothesized that cows housed on the CBP have good feet and leg health independent of bedding type, which may be related to increased lying time (Eckelkamp et al., 2013) and less time standing on concrete. Barberg et al. (2007b) observed cows housed on a CBP with higher scores of hock injury compared to the study by Shane et al. (2010); 25.2% of cows displayed hock lesions, 24.1% hair loss, and 1.0% swollen hocks. Researchers hypothesized the increased hock injury may be due to previous housing system injuries still present and healing after moving into the CBP barn. Klaas et al. (2010) studied CBP barns in Israel not using a supplemental bedding source and reported that cows displayed no hock
lesions or other lesions typically associated with freestall and tie-stall housing. In comparison, Weary and Taszkun (2000) reported 73% of cows with at least one hock lesion when housed in a freestall barn. Endres et al. (2005) observed low swollen hock prevalence of cows housed on deep-bedded SF (1.8%) but increased prevalence for cows housed on mattresses (14.1%).

**Hygiene and Mastitis.** Proper cow hygiene management can reduce mastitis risk (Neave et al., 1969, Philpot, 1979, Reneau et al., 2005, Schreiner and Ruegg, 2003). Conventional bedded pack systems are historically associated with poor cow cleanliness and increased mastitis risk (Berry, 1998, Peeler et al., 2000, Ward et al., 2002). Producers and scientists commonly transfer this mentality to the CBP barn system, assuming poor cow hygiene when housed in the system. Barberg et al. (2007b) observed a mean hygiene score (1 = clean and 5 = very dirty; Reneau et al., 2005) of 2.66 for the 12 CBP barns visited. Shane et al. (2010) observed a mean hygiene score (1 = clean and 5 = very dirty; Reneau et al., 2005) of 3.1 for six CBP barns. A study comparing CBP barns, CV barns, and NV barns noted that cows housed in CBP barns had increased ($P < 0.05$) hygiene scores (1 = clean and 5 = very dirty; Reneau et al., 2005)(3.33) in winter compared with the CV (2.72) and NV (2.78) barns (Lobeck et al., 2011). Furthermore, the researchers observed that hygiene score in the CBP barn increased in winter (3.33), likely due to the difficulty to manage a dry surface in the colder weather. Klaas et al. (2010) evaluated cow cleanliness in CBP barns in Israel, systems that do not add additional bedding material. Researchers determined 51.2% of cows scored as dirty (a score of 3 or 4), ranging from 10% to 90% for individual farms. One CBP generated higher temperatures and housed cleaner cows compared to two farms not generating
optimal composting heat. Researchers hypothesized that cow hygiene reflected compost performance. Fulwider et al. (2007) compared cow hygiene in CBP, MF, SF, and waterbed base freestall barns reporting similar hygiene scores for all systems (2.2, 2.2, 2.3, and 2.2, respectively).

Udder health, indicated by somatic cell count (SCC), improved in a study by Barberg et al. (2007b), where mastitis infection rate (percent of cows with SCC ≥ 200,000 cells/mL) reduced from 35.4% to 27.7% after moving into the CBP barn. Additionally, farms reported a mean SCC of 325,000 cells/mL, a value lower than the Minnesota state average. Researchers studying cow welfare differences between housing systems determined no statistical difference between mastitis prevalence (percent of cows with SCC ≥ 200,000 cells/mL) in CV, NV, and CBP barns (26.8%, 26.8%, and 33.4%, respectively)(Lobeck et al., 2011). Klaas et al. (2010) observed SCC of 133,000 cells/mL, 214,000 cells/mL, and 229,000 cells/mL for the three barns in Israel operating CBP barns without additional bedding added. Previous experimental results suggest the CBP barn provides the potential for excellent udder health with proper milking procedures.

**Producer Thoughts on the Compost Bedded Pack Barn System**

Producers cited improved cow comfort, through improved locomotion and foot and leg health, as the main reason to build the CBP barn (Barberg et al., 2007a, Janni et al., 2007, Shane et al., 2010). Additional benefits noted by producers include reduced capital investment when compared to a freestall facility, simplicity of daily chores, increased cow longevity, improved udder health and hygiene, and increased milk production (Barberg et al., 2007a, Barberg et al., 2007b, Janni et al., 2007, Klaas et al.,
2010). Producers did indicate some concerns with the housing system including limited bedding sources, high bedding cost, and increased dust level which may create respiratory issues (Barberg et al., 2007a, Barberg et al., 2007b, Shane et al., 2010). Overall, producers tended to be satisfied with the CBP barn system (Barberg et al., 2007a, Barberg et al., 2007b, Janni et al., 2007, Klaas et al., 2010).

**NEW DAIRY FACILITY ECONOMICS**

Investment decisions affect farm success by influencing farm profitability. Whether a farm is updating a barn, expanding, or starting a new dairy enterprise, choosing the most economically appropriate facility can dramatically influence profitability by improving or hindering milk production, cow comfort and health, or variable costs. Consultant advice, literature recommendations, and word of mouth typically dictate housing decisions, but each financial and management situation can dramatically affect the profitability of a decision. Not all producers’ management preferences are suited for every housing management system. Producer preference, financial status, geographic location, resource availability, and environmental considerations influence housing choice.

Economic models exist for different dairy decisions including reproduction (Demeter et al., 2011, Giordano et al., 2011, Giordano et al., 2012, Lassen et al., 2007, Plaizier et al., 1997), culling (Cabrera, 2010, 2012, Groenendaal et al., 2004, Marsh et al., 1987), nutrient management (Cabrera, 2010, Schils et al., 2007), farm machinery costs (Lazarus, 2009), anaerobic digesters (Lazarus et al., 2011), environmental emissions (Rotz et al., 2010), and mastitis (Charlier et al., 2012, Østergaard et al., 2005, Swinkels et al., 2005). Many of these decisions are made on a daily basis and others are made more
infrequently. The useful life of dairy housing is typically 15 to 20 y (Thomas et al., 1994), making housing investment decisions infrequent. However, Wisconsin dairy farmers are expected to spend nearly 50% of total expected investment dollars on new dairy facilities or upgrades from 2011 to 2015 ($535,440 of $1,180,080 expected dairy facility investment; NASS, 2010). Horner et al. (2007) produced models depicting 29 different dairy management situations. Each model varied by cow number (200, 700, or 3,000 cows), ventilation system (natural or mechanical), bedding type (CBP barn, MF barn, SF barn, or grazing), and manure handling system (manure pit, slurry scrape, or flush system). Knoblauch and Galton (1997) investigated the investment costs related to three different freestall housing systems and differing insulation levels. Lazarus et al. (2003) investigated the investment profitability of farmer’s continuing to milk in an existing tie-stall barn, expanding the existing tie-stall barn by 50%, or converting the existing tie-stall barn to a milking parlor and constructing a new freestall barn, or constructing all new milking a housing facilities. Continuing to milk in existing facilities projected a yearly income of $53,907. However, expanding that facility by 50% would not likely increase income enough because additional labor would be required. Converting the existing tie-stall barn to a milking parlor and building a new freestall barn would likely increase net farm income to $70,954 because of improved labor efficiency. Constructing all new facilities would improve labor efficiency and generate more income or $156,714; however, capital requirements would also increase substantially. The authors concluded that risk preference and credit worthiness influenced equity required to make a major farm investment. Producers using these models must choose a scenario
best matching their farm situation instead of using an interactive model that would allow flexibility in the values used to calculate investment profitability.

Common indoor dairy housing facilities include MF, SF, and CBP barns. Mattress based freestall barns allow each cow an individual stall to lie in. Each stall contains a mattress or waterbed, typically a heavyweight polyurethane cover filled with shredded recycled rubber or water, respectively, bedded with absorbent material 5.1 to 10.2 cm high, commonly sawdust or straw. Some farms use rubber mats, or other compressed material, as a mattress base, but these materials do not supply appropriate cushion when cows rise or lay down, possibly leading to increased hock lesions (Weary and Taszkun, 2000). Cows may move about the enclosed area, able to navigate freely to the feedbunk or waterer (MWPS, 2000). The SF barn is similar to the MF barn; however, instead of mattresses as a freestall base, stalls are hollow allowing for deep sand bedding with a 15.2 cm minimum depth (MWPS, 2000). The inorganic nature of sand reduces mastitis pathogen growth and exposure (Hogan et al., 1989, Kristula et al., 2005, Zdanowicz et al., 2004). Other materials commonly used for a deep-bedded stall include ground limestone, sawdust, straw, and recycled manure solids (MWPS, 2000). A CBP barn involves similar barn structural design, but the infrastructure is different. Instead of individual stalls, the pen area is an open area bedded with sawdust mixed with manure and urine (Janni et al., 2007). The bedded area provides a soft resting and standing area, potentially reducing lameness within the herd (Phillips and Schofield, 1994). The feed alley and milking facilities are typically the same as those observed in freestall barns (Janni et al., 2007).
A partial budget analysis assumes increases and reductions in income, and increases and reductions in costs due to a business change (Tigner, 2006). New dairy housing will likely increase bedding and feed costs, reduce labor and some animal health costs, and increase milk production. Parameters used to assess the economic viability of a housing option using a partial budget analysis include net present value (NPV) and internal rate of return (IRR). Net present value is the difference between added returns and costs incorporating the time value of money. The discount rate (DR), or the acceptable rate of return on an investment set by the producer, influences the NPV. When the NPV is greater than or equal to zero, the investment decision is considered economically viable, with the IRR having equaled or exceeded the DR. However, a NPV less than zero indicates an economically unviable investment decision, where the IRR did not meet the DR and benefits of the decision did not outweigh costs (Butler, 1996). Producers considering new dairy housing investment should consider each of these investment parameters before making an investment decision to better predict the profitability of the situation.

**CONCLUSIONS**

Producers developed the CBP barn concept to improve cow comfort and resolve some of the negative impacts of the BP barn. The CBP is a semi-composting system, which degrades a mixture of bedding material, manure, and urine while producing microbial heat to help dry the lying surface. Cows housed on the CBP may have improved feet and leg health and perform similarly to cows housed in freestall barns. The CBP contains high levels of mastitic bacteria; however, milk quality, as indicated by SCC, may not be negatively impacted. Producers choosing to construct a new CBP barn
should consider the amount of equity available, management preferences, and potential profitability of the system before investing in the system.
Figure 1.1. Cross-section of a bedded pack system described by Hindhede and Enevoldsen (1993). Figure depicts feedbunk separated from bedded pack by alleyway.
Figure 1.2. General compost bedded pack barn layout described by Janni et al. (2007).
Figure 1.3. Sun angles of a north-south oriented dairy barn described by Smith et al. (2001).

Sun Angles for N-S Freestall - August 21st
40 Degrees North Latitude (Omaha - Springfield)
Figure 1.4. Sun angles of an east-west oriented dairy barn described by Smith et al. (2001).

Sun Angles for E-W Freestall - August 21st

40 Degrees North Latitude (Omaha - Springfield)
CHAPTER TWO

Compost bedded pack dairy barn management, performance, and producer satisfaction

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INTRODUCTION

In the mid-1950s, producers established a dairy cattle housing facility, a conventional bedded pack (BP) barn, which allowed cows to lie on a bedded manure pack and to be milked in a separate milking facility (Bickert and Light, 1982). However, some negative factors are associated with the bedded pack, including increased intramammary infection risk (Berry, 1998, Fregonesi and Leaver, 2001, Peeler et al., 2000), increased gaseous emissions (Mosquera et al., 2006, Snell et al., 2003), and possible respiratory problems. Virginia dairy farmers developed the compost bedded pack (CBP) barn concept to improve cow comfort, increase cow longevity, and reduce initial barn cost (Wagner, 2002) while potentially reducing the mastitis risk associated with the BP. Producers used the BP system layout and incorporated composting methods.

Facility design can govern the success or failure of the composting process and design considerations are important for efficient composting. Compost bedded pack barns provide an open resting area free of stalls or partitions, often surrounded by a 1.2 m retaining wall to support manure storage for at least six to 12 mo (Janni et al., 2007). To compensate for the loss in sidewall opening due to the retaining wall, eaves should be built at 4.9 m high instead of the typical 3.7 m height recommended for freestall barns (Janni et al., 2007). This increase in height improves natural ventilation and ensures equipment can access the barn as the CBP height increases (Janni et al., 2007). Site location and barn orientation affect natural ventilation rates (Chastain, 2000) and the amount of sunlight that penetrates the barn interior (Smith et al., 2001).
Temperature is a key composting efficiency measure (Imbeah, 1998). Active compost material aeration supports microbial heat production. Milking typically occurs two times per d, which presents a convenient time to stir the CBP without cows occupying the CBP (Barberg et al., 2007a, Janni et al., 2007, Shane et al., 2010). Compost temperatures between 40 and 50 °C achieve the most cellulose degradation (Fergus, 1964, Jeris and Regan, 1973, Kuter et al., 1985), potentially leading to greater CBP height reduction and increased manure storage length. Higher temperatures (55 to 65 ºC) promote pathogen destruction (Stentiford, 1996), which may be advantageous for mastitis-causing bacteria reduction. However, CBP temperatures observed by Barberg et al. (2007a) and Klaas et al. (2010) did not reach the level necessary for material sanitization. The lack of material sanitization during the microbial processes in the CBP indicates the system is more of a “semi-composting” system that does not fully cycle through the entire composting process. Higher temperatures also increase moisture evaporation (NRAES, 1992). Manure, urine, and microbial activity moisture act as moisture sources in a CBP (Janni et al., 2007). The combination of manure, urine and bedding should not exceed a moisture content of 70% (Gray et al., 1971a, Schulze, 1962), though a range of 50 to 60% is preferred (Gray et al., 1971b, NRAES, 1992, Suler and Finstein, 1977).

Optimal cow stocking density depends on the amount of manure and urine deposited into the CBP. More moisture deposited by cows requires either more space per cow or more bedding to absorb the moisture, allowing for microbial activity and surface drying to be active and balanced (Janni et al., 2007). At minimum, all cows must be able to lie down at the same time while still allowing space for cows to travel to the feedbunk.
or waterer (Janni et al., 2007). Assuming an average 590 kg Holstein cow, a lying space of 259.1 cm long and 132.1 cm wide is required (Anderson, 2009), resulting in a minimum lying space of 3.4 m²/cow. Additional space for standing requires 50.8 cm of lunge space, meaning each cow needs 4.1 m² of living space. Wagner (2002) originally recommended 9.4 m²/cow in CBP barns. However, based on the manure and urine output of a cow, Janni et al. (2007) recommended 7.4 m²/cow for a 540 kg Holstein cow or 6.0 m²/cow for a 410 kg Jersey cow. Israeli barns using no additional bedding required greater space per cow to account for the reduced water holding capacity, recommending a minimum of 15 m²/cow when the feed alley was scraped and between 20 and 30 m²/cow when compost was used in the feed alley (Klaas et al., 2010).

Cow density, ambient weather conditions, air flow, and cow hygiene are major factors that affect the need for new bedding addition (Barberg et al., 2007a, Janni et al., 2007). Compost bedded pack barn managers use fine wood shavings or sawdust, which are suspected to improve mixing, and aeration along with microbial activity from increased surface area to volume ratio compared with straw and woodchips (Janni et al., 2007). Janni et al. (2007) recommended avoiding green or wet sawdust or shavings because of possible increased teat end exposure to Klebsiella bacteria (Bagley et al., 1978, Fairchild et al., 1982, Newman and Kowalski, 1973). In Minnesota, rising sawdust costs and supply shortages increased interest in alternative bedding sources (Shane et al., 2010). Shane et al. (2010) investigated alternative bedding sources, including wood chips, flax seed, wheat straw, oat hulls, and soybean straw, concluding that all the materials studied increased CBP temperature similarly to sawdust. Kapuinen (2001a) studied alternative bedding sources in deep litter composting systems for beef cattle
including peat, straw, and wood chips. A straw and peat mixture, with peat not exceeding 60% of the mixture, proved to act as a sufficient litter mix for composting due to presence of high temperature and mass loss of the bed.

The CBP has the flexibility to meet the space, exercise, resting, and social needs of cows (Galama et al., 2011), making it a promising housing system to promote animal well-being compared to freestall facilities. The CBP is free of concrete alleys in the resting area and cows walk, stand, and rest on compost (Barberg et al., 2007a). Lobeck et al. (2011) discovered lower lameness incidence (locomotion score > 2, where 1 = normal and 5 = severely lame; Flower and Weary, 2006) in CBP barns (4.4%) compared with cross-ventilated (CV) (13.1%,  $P = 0.01$) and naturally ventilated (NV) (15.9%,  $P < 0.001$) freestall barns. Barberg et al. (2007b) observed similar results, where 7.8% of cows housed on the CBP exhibited clinical lameness. Cook (2003) discovered lower mean lameness prevalence among herds with sand freestalls (SF) (summer prevalence: 16.5%; winter prevalence: 18.9%) compared to freestall herds using mats or mattresses (summer prevalence: 24.4%; winter prevalence: 26.9%), both of which had values greater than those observed in CBP barns.

Proper cow hygiene management can reduce mastitis risk (Neave et al., 1969, Reneau et al., 2005, Schreiner and Ruegg, 2003). Barberg et al. (2007b) observed a mean hygiene score (1 = clean and 5 = very dirty; Reneau et al., 2005) of 2.66 for 12 CBP barns visited. Shane et al. (2010) observed a mean hygiene score (1 = clean and 5 = very dirty; Reneau et al., 2005) of 3.1 for six CBP barns. A study comparing CBP barns, CV barns, and NV barns noted that cows housed in CBP barns had increased ( $P < 0.05$) hygiene scores (1 = clean and 5 = very dirty; Reneau et al., 2005)(3.18) compared with
the CV (2.83) and NV (2.77) barns (Lobeck et al., 2011). Udder health, indicated by SCC, improved in a study by Barberg et al. (2007b), where mastitis infection rate (percent of cows with SCC ≥ 200,000 cells/mL) reduced from 35.4% to 27.7% after moving into the CBP barn. Klaas et al. (2010) observed SCC of 133,000 cells/mL, 214,000 cells/mL, and 229,000 cells/mL for the three Israeli CBP barns without additional bedding added.

The primary objective of this study was to define key management strategies employed by Kentucky farmers operating CBP barns and CBP influences on cow udder health and hygiene, lameness, and performance. The second study objective was to determine factors that influence CBP temperature and moisture and cow hygiene.

MATERIALS AND METHODS

A field survey of 47 routinely aerated CBP barns was conducted in Kentucky between October 2010 and March 2011. Of the 47 barns, 34 barns were used as the primary housing facility for lactating cows. The remaining 13 barns were used as supplemental housing for special needs cows (i.e. lame, old, and sick cows).

Data Collection

A survey was used to assess management practices (Appendix 2.1). Performance records from DHIA, including milk production, SCC, culling, and reproductive performance, were collected with producer permission from farms enrolled in the program. Only herds with 12 mo of data before and 24 mo of data after barn occupancy were included in the DHIA analysis. Fourteen farms met this criterion. Historical bulk-tank SCC (BTSCC) was collected from cooperatives and milk companies with producer
permission. Farms without data before and after barn occupation were excluded from the analysis. Twelve of the 42 producers were included in the BTSCC analysis.

**Herd Locomotion and Hygiene.** Locomotion and hygiene scores were collected for cows on each farm using the CBP barn as the primary housing facility (N = 34). A minimum of 50 cows were scored on each farm unless fewer than 50 cows were housed in the CBP, in which case, all cows were scored. Cows were randomly selected using the last digit of the ear tag number (e.g. even number, odd number, multiple of three) and scored for both locomotion and hygiene by the same observer at each farm visit.

Lameness was assessed using the Sprecher et al. (1997) locomotion scoring system where 1 = normal, 2 = mildly lame, 3 = moderately lame, 4 = lame, and 5 = severely lame. Locomotion observation was performed by encouraging the animal to move and evaluating the legs and back. Cows with locomotion score ≥ 3 were classified as clinically lame. Hygiene was evaluated using a system ranging from 1 to 4 where 1 = clean and 4 = filthy (Cook and Reinemann, 2007).

**Compost Nutrient Analysis.** Bedding material samples were collected from nine evenly distributed locations throughout each barn (Figure 2.1). Researchers collected 118.3 cm$^3$ of surface layer bedding material from each location (total of 1,064.7 cm$^3$) using a 59.1 cm$^3$ measuring cup (Everyday Living™, The Kroger Co., Cincinnati, OH) in a 3.8 L plastic bag (Ziploc®, Slider Storage and Freezer Bags with SmartZip® Seal, Racine, WI) and thoroughly mixed the material to create a composite sample representative of the entire CBP. Bedding material nutrient analyses were performed by University of Kentucky Regulatory Services laboratory personnel on all bedding material samples to determine moisture, P, K, Ca, Mg, Zn, Cu, Mn, and Fe concentrations by
methods specified by Peters et al. (2003). The carbon to nitrogen ratio (C:N) was calculated for all barns.

**Building Envelope.** Building measurements included: building orientation and location (longitude and latitude); barn length and width; CBP length and width; feed alley length; waterer length, width, location, and number; eave height; ridge opening and type; and fan number and location (Damasceno, 2012).

**Compost Bed Temperatures.** Temperatures were collected once during each site visit at nine evenly distributed locations within the barn (Figure 2.1). Temperature collection occurred at 10.2 and 20.3 cm deep using a thermocouple-based thermometer (0.22 m length, accuracy of ± 2.2°C; Fluke Inc., model 87, Everett, WA, USA), and the CBP surface using an infrared thermometer (accuracy of ± 1°C; Fluke®, model 62, Everett, WA, USA). Ambient temperature and relative humidity (RH) conditions were collected once at each site visit using a weather meter (accuracy of ±1°C; Kestrel®, model 4000, Sylvan Lake, MI, USA).

**Statistical Analysis**

**Descriptive Statistics.** The MEANS procedure of SAS® (SAS 9.3, SAS Inst. Inc., Cary, NC) was used to calculate means and standard deviations (SD) of all non-categorical management practices, locomotion scores, hygiene scores, ambient and internal barn temperatures and RH, CBP temperatures, and nutrient concentrations. All means are reported as mean ± SD. The FREQ procedure of SAS® was used to calculate producer comment and management practice frequencies.

**Herd Performance.** The MIXED procedure of SAS® (SAS 9.3, SAS Inst. Inc., Cary, NC) was used to develop models to describe DHIA data for herds using the CBP
barn as a primary housing facility and a special needs housing facility. Performance metrics, including milk production, SCC, culling, and reproductive performance, were compared for the 12 mo before (before), 1 to 12 mo after (transition), and 13 to 24 mo after (after) moving into the CBP barn.

Seasons were defined as follows: March 20, first d of spring; June 21, first d of summer; September 22, first d of fall; and December 21, first d of winter. Daily herd BTSCC were averaged by mo and categorized as mo one to 12 before or after the barn occupation date. The MIXED procedure of SAS® was used to test the influence of the transition to the new facility (before or after) and season on BTSCC for producers using the CBP barn as a primary housing facility or for special needs cows.

**Temperature, Moisture, and Hygiene.** The GLM procedure of SAS® (SAS 9.3, SAS Inst. Inc., Cary, NC) was used to develop models to describe CBP moisture, 20.3 cm CBP temperature, and cow hygiene. Four farms were excluded from the analysis because cows had access to both a CBP barn and freestall barn, creating inaccurate stocking density estimations. An additional six farms were excluded from the moisture model because relative humidity data was not collected. Explanatory variables for CBP moisture included stirring depth, pasture access adjusted space per cow (SQPM), and drying rate. Space per cow was adjusted for pasture access and calculated using Eq. 2.1 to account for the reduced moisture deposits from manure and urine when cows spent less time on the CBP. Pasture access was a producer estimate and may not represent the actual time on pasture.

\[
\text{SQMP} = \frac{\text{SQM}}{1 - \text{PAST}} \quad \text{(Eq. 2.1)}
\]
Where SQMP = space per cow (m$^2$/cow) adjusted for pasture access, SQM (m$^2$/cow) = total CBP area divided by the number of cows housed on the CBP, PAST = percent of time (expressed as a decimal) cows spent on pasture during the day at the time of the site visit. Drying rate was calculated using Eq. 2.2, accounting for the effects of air temperature, air water holding capacity, and air velocity on CBP moisture.

$$\text{DR} = K \times \Delta \text{WHC}$$  \hspace{1cm} (Eq. 2.2)

Where DR = drying rate (kg H$_2$O/m$^2$ • s), K = mean overall mass transfer coefficient which is a function of air velocity (AV) (m/s), and ambient temperature (AT) (°C), where air velocity was raised to the 0.5 power and ambient temperature was raised to the 0.67 power, ΔWHC = change in water holding capacity (WHC) between the surface of the CBP and 121.9 cm above the CBP. Change in WHC was calculated using equation 2.3 (Bird et al., 1960).

$$\Delta \text{WHC} = \left( \frac{\text{HR}_{\text{SUR}}}{\text{SV}_{\text{SUR}}} - \frac{\text{HR}_{\text{AIR}}}{\text{SV}_{\text{AIR}}} \right)$$ \hspace{1cm} (Eq. 2.3)

Where ΔWHC = change in WHC, HR$_{\text{SUR}}$ = humidity ratio (kg H$_2$O/kg dry air) of the CBP surface (a function of the CBP surface absolute temperature (K), assuming 100% relative humidity (RH) (%)), SV$_{\text{SUR}}$ = specific volume (m$^3$/kg) of the CBP surface (a function of the CBP surface temperature (°C), assuming 100% RH), HR$_{\text{AIR}}$ = humidity ratio (kg H$_2$O/kg dry air) of the atmosphere 121.9 cm above the CBP surface (a function of the ambient temperature and RH (%) 121.9 cm above the CBP surface), SV$_{\text{AIR}}$ = specific volume (m$^3$/kg) of the atmosphere 121.9 cm above the CBP surface (a function of the ambient temperature and RH (%) 121.9 cm above the CBP surface).

Explanatory variables for CBP temperature included stirring frequency, stirring depth, ambient temperature, and space per cow. Explanatory variables describing cow
hygiene included ambient temperature, CBP moisture, and 20.3 depth CBP temperature. Only farms using the barn as the primary housing facility were included in the hygiene analysis (n = 32). Quadratic and cubic transformations were tested for all explanatory variables \((P < 0.05)\). All explanatory variables and two- and three-way interactions between explanatory variables and significant transformations were tested \((P < 0.05)\) using backward elimination and Type I sums of squares.

RESULTS AND DISCUSSION

Farm Management

Herd Characteristics and Management. During the site visits, 90.1 ± 41.8 cows were housed in CPB (n = 47). Producer-reported daily milk production and SCC were 27.3 ± 4.0 kg (n = 39) and 246,500.0 ± 84,421.6 cells/mL (n = 38), respectively. The USDA/NASS (2012a) reported daily milk production in Kentucky as 17.8 kg/d, lower than that reported by producers using the CBP barn. Norman et al. (2010) reported mean SCC in Kentucky of 313,000 cells/mL, 66,500 cells/mL higher than the value reported for farms using CBP barns. Cow breeds were Holstein (n = 29), Jersey (n = 3), and a mixture of different breeds (n = 9). Farms predominately fed total mixed rations (TMR) (n = 36), though some practiced component feeding (n = 5) or a mixture of component feeding and a TMR (n = 1). In the summer, 25 producers operated a zero grazing system while 27 producers operated a zero grazing system in the winter. Twenty farms pastured cows during the summer a mean of 40.3 ± 17.3% of the d; however, 20 producers pastured cows during the winter a mean of 37.4 ± 19.2% of the d. Allowing pasture access reduces the amount of urine and manure voided while in the barn, reducing bedding requirements.
Farms handled hoof problems through regular hoof trimming (n = 35), treating foot problems in the parlor (n = 29), and footbath use (n = 23). Most producers stated that papillomatous digital dermatitis incidence, or hairy heel warts, either did not change (n = 22) or decreased (n = 3) after transitioning to the CBP barn. Ten producers reported an increase in hairy heel wart incidence. Compost bedded pack moisture conditions likely play a role in hairy heel wart prevalence and incidence is likely to increase if a dry standing surface is not maintained (Wells et al., 1999). Several farms (n = 16) moved into the CBP barn from a pasture-based system, increasing time spent on concrete while at the feed bunk. Increased time spent on concrete and standing in liquid manure slurry may increase hoof exposure to moisture irrespective of composting conditions. Most producers did not dock cow tails (n = 31), though some producers docked all tails (n = 6) and others docked some tails (n = 4).

Culling criteria consisted of reproductive performance problems (n = 32), poor feet and leg health (n = 8), mastitis (n = 6), age (n = 6), production (n = 6), and sold to other dairies (n = 2). Other culling criteria (n = 1) included injuries, SCC, transition problems, over capacity, udder conformation, calving problems, Johne’s disease, and other diseases. Most producers used artificial insemination (AI) (n = 27) rather than a bull (n = 23) to breed cows and four producers used a bull for cleanup after using AI. One producer was a seasonal breeder. Producers used visual observation of heat most frequently (n = 22) to detect estrus in cows. Other heat detection means included Ovsynch (n = 11), Estrotect™ heat detector patches (Rockway, Inc., www.estrotect.com) (n = 8), tail paint (n = 6), Lutalyse® (Pfizer Animal Health, New York, NY) (n = 6), Kamar Heatmount Detectors (Kamar, Inc., Colorado Springs, CO) (n = 5), a timed AI
protocol (n = 4), another heat alert system (n = 2), or CIDRs (n = 1). Eleven producers relied on the bull for estrus detection.

**Previous Housing and New Housing Influences.** Most producers moved to a CBP barn from pasture (n = 16) or a freestall barn (n = 12), with others moving from a freestall and pasture system (n = 6), a conventional bedded pack and pasture system (n = 4), or a conventional bedded pack and freestall system (n = 1). Gathering ideas from touring barns influenced barn design for many producers (n = 21). Other influences included producer ideas (n = 8), university literature (n = 8), industry concepts (n = 4), freestall barn designs (n = 3), and National Resource Conservation Service (NRCS) designs (n = 2). Building a CBP barn with the same recommendations as a freestall barn allows flexibility to convert the barn to freestalls if the barn does not suit the producer’s needs. Not every system suits every producer and a desire to transition the CBP barn to a freestall barn for management preference purposes may arise. The flexibility in barn dimensions will allow that transition. However, adjusting the recommendations to optimize composting environment success (Janni et al., 2007) is important to maintaining a dry lying surface for cows.

**Compost Bedded Pack Management.** Most producers used wood shavings or sawdust as bedding material for their CBP barn. Fifty percent used kiln-dried shavings or sawdust, 33% used green sawdust, and 17% used a combination of green, kiln-dried, or other non-wood shavings. Producers did not report an increase of *Klebsiella* or coliform mastitis cases, even with green sawdust use. Janni et al. (2007) recommended avoiding green or wet sawdust or shavings because of possible increased teat end exposure to *Klebsiella* bacteria, a cause of environmental mastitis. Fairchild et al. (1982) reported
increased *Klebsiella* levels in fresh sawdust bedding samples compared to the same used sawdust bedding samples (Wk 1: 281.8 x 10^4 cfu/g; Wk 9: 0.6 x 10^4 cfu/g). However, these differences were not significant (*P* > 0.05). *Klebsiella* species survive in hardwood and sapwood (Bagley et al., 1978) and not heating the wood used for bedding may increase udder exposure to these pathogens. Newman and Kowalski (1973) reported 3 of 4 sawdust samples and 29 of 54 milk samples contained *Klebsiella* species. However, only a few cows exhibited any clinical or subclinical mastitis signs. *Klebsiella* species fecal shedding may also create conditions conducive to increased mastitis incidence. In a study by Munoz et al. (2006), 80% of 100 cows sampled tested positive for *K. pneumoniae*. Furthermore, Verbist et al. (2011) determined contamination of bedding to be mostly from fecal shedding of *K. pneumoniae*. Green sawdust may increase exposure to *Klebsiella* species, but other environmental sources may also contribute to mastitis incidence caused by *Klebsiella* species. Using kiln-dried shavings, finding an alternative bedding source, or maintaining a clean, dry resting environment may reduce exposure to *Klebsiella* species. The current study did not measure clinical mastitis prevalence. Therefore, changes in mastitis caused by *Klebsiella* bacteria due to bedding choices are unknown.

Producers added shavings at a depth of 25.1 cm (n = 35), ranging from 3.5 to 121.9 cm, to begin a new CBP. Winter weather required new shavings addition every 16.4 d (n = 40), ranging from every d to every 56 d. Summer weather required new shavings every 18.2 d (n = 39), ranging from every other d to every 45 d. Producers added a mean depth of 8.8 cm (n = 40) of shavings per bedding addition, ranging from 0.1 cm to 35.3 cm. Colder weather increases the temperature gradient between ambient
air and the CBP. The increased gradient may increase CBP cooling, reducing CBP
temperatures, and decreasing moisture evaporation (NRAES, 1992). Most producers
added shavings to reduce CBP moisture (n = 25), indicating increased need for bedding
in the winter season. Criteria for shavings addition included compost sticking to the
cows (n = 12), visual observation of the CBP (n = 9), dirty cows (n = 6), a routine
addition schedule (n = 5), compost compaction (n = 3), compost sticking to equipment (n
= 3), bedding availability (n = 1), or cow lying behavior changed (n = 1). Other reports
have recommended bedding addition when material sticks to the cows (Barberg et al.,
2007a, Janni et al., 2007); however, hygiene was likely compromised and SCC may have
already increased at this point. Instead, adding shavings based on CBP moisture is a
more viable recommendation. The combination of manure and substrate should not
exceed a moisture content of 70% (Gray et al., 1971a, Schulze, 1962), though a range of
50 to 60% is preferred (Gray et al., 1971b, NRAES, 1992, Suler and Finstein, 1977).

Barn cleanout occurred 1.7 ± 0.8 times per y (n = 30) when the CBP reached 0.9
± 1.5 m (n = 22) in height. A height of 7.9 ± 10.9 cm (n = 30) of bedding material
remained in the barn after barn cleanout. The top CBP layer has an active microbial
population and using that layer to begin a new CBP may result in a smoother transition
between CBP cleanout.

Producers allotted 9.0 ± 2.2 m² of CBP space per cow (n = 44). When adjusted
for pasture access, space per cow was 12.0 ± 7.6 m² of CBP space per cow. Barberg et
al. (2007a) reported a stocking density of 8.6 ± 2.6 m² per cow and Janni et al. (2007)
recommended a minimum of 7.4 m² per cow. Summer weather allows for more
evaporative drying without the risk of overcooling the CBP, which can easily occur in
cooler weather. Providing more space in winter weather reduces the amount of moisture per area of space and may reduce the need for bedding supply.

Most producers (n = 28) stirred the CBP 2X per d in the summer while 18 producers stirred the CBP 1X per d and one producer stirred the CBP 3X per d. In the winter, 33 producers stirred the CBP 2X per d, 13 producers stirred 1X per d, and one producer stirred 3X per d. Stirring depth was 24.2 ± 7.4 cm (n = 42). Frequent CBP aeration supplies oxygen to CBP aerobic microbes and bacteria, stimulating microbial activity and metabolic heat. Heat from the CBP dries the surface layer, providing a dry resting surface for cows and reducing the need for additional bedding. Field cultivators were the most frequently used tool for stirring (n = 33), followed by rototillers (n = 5) and a combination of rototillers and cultivators (n = 4). Thirty-three percent of producers monitored CBP temperature with a thermometer (n = 40).

Most alleys were scraped clean 1X per d (n = 18), but seven producers scraped 2X per d, four scraped once every other d, and one scraped 3X per d. Producers used tire scrapers (n = 26) and box blades (n = 3) to clean alleys. An earthen lagoon was the most common manure storage system (n = 25) for excrement deposited in the feed alley, holding pen, and milk parlor, but some producers also used stack pads (n = 4) and concrete pits (n = 2).

**Parlor and Milking Procedures.** Parlor types included herringbone (n = 22), parallel (n = 10), parabone (n = 5), rapid exit (n = 1), swing (n = 1), walkthrough (n = 1), bypass (n = 1) and a flat barn (n = 1). Most farms milked cows 2X per d (n = 38) and four farms milked cows 3X per d. Milking procedures were posted in 12.2% (n = 41) of parlors. Glove use during milking occurred in 75.6% of farms (n = 41). Ninety-eight
percent of producers (n = 42) used pre-dip and all producers used post-dip (n = 42). Pre-dips used include iodine (n = 20), hydrogen peroxide (n = 5), sodium dichloroisocyanurate (n = 3), and chlorine dioxide (n = 1). Post-dips used include iodine (n = 25), sodium chlorite (n = 3), chlorine dioxide (n = 3), and a combination of iodine and sodium chlorite (n = 1). All producers (n = 41) dried teats before attaching the milker and 82.9% of producers (n = 41) used individual towels for each cow. Automatic takeoffs were employed on 61.0% of the farms (n = 41) visited. Most farms had their milking systems analyzed annually (92.3%, n = 39). Culturing of mastitic cows occurred for 43.9% of farms and 43.9% did not culture and 12.2% cultured based on the case (n = 41). Proper parlor procedures, especially the use of a post-milking teat disinfectant, and properly functioning equipment are crucial for any management system in maintaining healthy udders (Dufour et al., 2011).

**Dry Cow Management.** All but one farm used dry cow antibiotic therapy (n = 42). All four quarters were treated by 85.3% of producers (n = 34) and 41.5% (n = 41) used Orbeseal® (Pfizer Animal Health, New York, NY). Fifty-one percent of producers (n = 41) used an *Escherichia coli* vaccine including J-5 Strain (Pfizer Animal Health, New York, NY) (n = 9), ENDOVAC Bovi® (IMMVAC, Inc., Columbia, MO)(n = 7), and J-VAC® (Merial, Duluth, GA)(n = 4). Twenty-nine farms managed dry cows on pasture or an exercise lot and five farms provided housing for dry cows.

**Economics.** Building costs can be a major capital investment when constructing new housing. Compost bedded pack barns have lower investment costs compared to freestall barns because of reduced concrete requirement and the lack of stall hardware (Barberg et al., 2007a, Black et al., 2012, Janni et al., 2007), though some states do
require a concrete base to reduce nutrient seepage. However, more space per cow is necessary requiring a larger structure to handle the moisture input from manure, urine, and microbial moisture in the CBP.

Total barn construction cost for the CBP was $85,362 ± 69,791 (n = 37). Many producers renovated old barns and did not require an attached feed alley or used the CBP barn as supplementary housing for special needs cows and allowed cows to eat at a separate location. Additionally, some producers preferred an unattached feed alley and chose not to incorporate the feed alley into the CBP barn. Producers that built the CBP barn with an attached feed alley spent $103,729 ± 74,209 (n = 24) on total barn construction to house 103.3 ± 63.3 cows, spending $78.77 ± 29.12 per m² of barn area. Producers that chose to build the CBP barn without an attached feed alley spent $51,454 ± 46,229 (n = 13) on total barn construction to house 98.8 ± 46.9 cows, spending $48.69 ± 21.01 per m² of barn area. Concrete can account for a substantial portion of barn construction costs and eliminating the feed alley from barn construction can eliminate a portion of those costs. Barn costs per cow (assuming 9.3 m² per cow) were $1051 ± 407 (n = 24) with a feed alley attached and $493 ± 196 (n = 13) without an attached feed alley. However, producers did not always supply 9.3 m² per cow. Barns with an attached feed alley supplied 9.2 ± 2.0 m² per cow (n = 24). Barns without an attached feed alley supplied 8.9 ± 2.7 m² per cow (n = 13). Using producer supplied space per cow, CBP barns with an attached feed alley cost $1013 ± 383 per cow (n = 24) and barns without an attached feed alley cost $511 ± 312 per cow (n = 13).

Horner et al. (2007) produced models depicting 29 different management situations. Each model varied by cow number (200, 700, or 3,000 cows), ventilation
system (natural or mechanical), bedding type (CBP barn, mattress base freestall (MF) barn, sand base freestall (SF) barn, or grazing), and manure handling system (manure pit, slurry scrape, or flush system). Mattress and sand freestall barns cost $1,950 per cow and $1,800 per cow, respectively, including lights, loops, mats, and cooling. Comparing this to the similar CBP barn scenario, where a feed alley is included in the barn, the CBP costs $900 or 46% less per cow than the MF barn and $750 or 42% less per cow than the FS barn. However, though the initial investment cost is lower than the freestall systems, the variable cost associated with CBP bedding may be higher.

Sawdust bedding cost $6.55 ± 4.72 per m³ for all materials used including kiln-dried sawdust or shavings (KDS), green sawdust or shavings (GS), and a mixture of kiln-dried sawdust or shavings, green sawdust or shavings, or an alternative material (MIX). Producers using a MIX paid more for bedding ($9.45 ± 4.96 per m³) than producers using KDS ($8.19 ± 4.95 per m³) and GS ($3.30 ± 1.91 per m³). Additionally, producers using a MIX added more shavings to the CBP per d (6.31 ± 5.18 m³ per d) than producers using KDS (3.29 ± 3.23 m³ per d) and GS (4.92 ± 5.27 m³ per d). A MIX cost $0.70 ± 0.49 per cow per d, KDS cost $0.35 ± 0.37 per cow per d, and GS cost $0.26 ± 0.32 per cow per d. The MIX material may be higher in cost because producers required additional bedding due to reduced water holding capacity of the green or alternative bedding material.

A SF barn requires 18.2 kg of sand per stall per d (Gooch et al., 2003) and sand bedding costs $0.0099 per kg (Buli et al., 2010). Assuming cows were stocked to allow one stall for every cow, FS bedding cost $0.18 per cow per d. Sand freestalls are deep bedded stalls, which require a minimum depth of 15.2 cm (MWPS, 2000) to provide a comfortable lying surface. Mattress freestalls require less bedding because the mattress
acts as the soft laying surface instead of the bedding. Bedding aids in reducing abrasive forces when the cow rises and lies down. A minimum of 2.5 to 5.1 cm of bedding is recommended on the mattress surface (MWPS, 2000), added 3.9 times per wk (Fulwider et al., 2007). An average 590 kg Holstein cow requires a mattress that is 114.3 cm wide and 172.7 cm long. If producers add 3.8 cm of bedding, stalls will require 0.075 m$^3$ of sawdust bedding. Producers bedding freestall barns likely use a variety of different sawdust materials similar to the CBP barn costing $6.55 \text{ per m}^3$. Therefore, MF bedding cost $0.13 \text{ per cow per d}$. The MF system requires the least amount of bedding material investment; however, bedding costs vary depending on region and hauling distance from the source.

**Producer Comments**

Producers were asked to comment on whether they were satisfied with their barn, aspects of the CBP barn they liked, aspects they would change, recommendations to other farmers, and lessons learned throughout their time managing the CBP barn. Of the 42 producers, 41 responded that they were satisfied with their CBP barn and one responded he was somewhat satisfied; however, producers tend to retrospectively support a decision after a large investment. Most producers cited increased cow comfort as a benefit to the CBP barn system (Table 2.1, n = 28). Others cited increased cow cleanliness (n = 14), the low maintenance nature of the system (n = 10), and the barns usefulness for special needs and problem cows (n = 10). Additional cited benefits include (n = 1): lower bedding cost, cleaner pastures, lower investment cost, fewer odors, and fewer flies. When asked what they would change about their CBP barn (Table 2.1), the most frequently cited changes included increased size or capacity (n = 15), higher sidewalls
and improved ventilation (n = 12), the addition of a retaining wall (n = 6), more fans (n = 5) and curtains in the winter (n = 5). Additional recommended changes included (n = 1): adding a close-up pen, adding sprinklers, adding rubber mats to alleyways, increasing feed alley width, changing stirring equipment, and positioning the lagoon near the barn. Eleven producers recommended that producers considering building a CBP barn (Table 2.1) secure an adequate bedding supply. Other recommendations included stirring the CBP 2X per d (n = 9), using kiln-dried shavings (n = 6), maintaining the CBP and keeping moisture low (n = 5), and supplying 9.3 m² per cow (n = 5). Producer reported recommendations and facility changes often contradict one another implying a need to better understand the CBP system and variability among farmer’s management practices.

Compost Characteristics

Compost Nutrient Analysis. Table 2.2 depicts CBP nutrient compositions. Carbon to nitrogen ratio ranged from 11.3 to 43.2 with a mean of 26.7 ± 7.8. Barberg et al. (2007a) observed a mean C:N of 19.5 in CBP barns in Minnesota and Russelle et al. (2009) observed a range of 11.2 to 20.9 in CBP in Minnesota, both less than the values observed for the current study. The current study may have a higher C:N ratio due to increased bedding availability in Kentucky compared to Minnesota. The difference may also be related to Kentucky farms having an advantage of a larger body of literature to use when planning and constructing the new facility. The mean C:N in the current study was within the recommended range of 25:1 to 30:1 for optimal composting (NRAES, 1992). In contrast, Qian and Schoenau (2002) found a negative relationship between C:N in the compost at the time of application as fertilizer, and nitrogen availability to the soil, stating that a C:N greater than 15 tended to decrease nitrogen availability. This suggests
the need for continued CBP material composting once removed from the barn to further process the material to a more usable product. Processing the material further will allow the material to be sanitized through high microbial heat generation and further degraded by mesophilic microbial digestion. Alternative beddings do have the ability to produce C:N ratios suitable for composting (Shane et al., 2010), though producers preferred using sawdust. Using alternative beddings, even if mixed with sawdust or wood shavings, can provide producers more opportunities for cheaper bedding materials while still maintaining an active composting environment. The alternative bedding, however, must provide adequate surface area for optimal degradability and adequate C:N ratio. In addition to C and N, the CBP samples (Table 2.2) contained 0.40 ± 0.15% of P, 1.30 ± 0.52% of K, 2.01 ± 3.15% of Ca, 0.45 ± 0.21% Mg, 110.37 ± 45.91 ppm of Zn, 27.76 ± 15.53 ppm of Cu, 222.41 ± 135.00 ppm of Mn, and 2,779.73 ± 2,339.44 ppm of Fn. Most manure contains sufficient nutrient concentrations to satisfy crop needs; however, testing soil to determine nutrient contents may be beneficial for not over- or under-applying nutrients.

**Temperature.** Mean collection and ambient temperature was 9.9 ± 9.4 °C. The mean CBP temperature at the surface was 10.5 ± 8.0 °C. Evaporation and ventilation cool the CBP surface bringing the CBP temperature level near that of ambient temperature. However, at a CBP depth of 20.3 and 10.2 cm, temperatures were 36.1 ± 11.0 °C, and 32.3 ± 10.6 °C, respectively. The CBP can maintain higher temperatures deeper in the CBP because fewer cooling mechanisms exist. Barberg et al. (2007a) reported a higher mean CBP temperature of 42.5 °C across 12 barns and four depths (15, 30.5, 61, and 91 cm) studied in Minnesota. They noted that temperatures were not
significantly different across different depths in the CBP. Compost bedded pack temperatures were higher than reported in the current study. Barberg et al. (2007a) took temperatures from greater depths than the current study, which may have led to higher CBP temperatures. Additionally, more locations were sampled, possibly reducing the impact of a low temperature on the overall mean. A similar study conducted in Israel by Klaas et al. (2010) observed a CBP temperature range between 25 and 42 °C, an increase ranging from 7 to 24 °C above ambient temperature, for one CBP barn not using an additional bedding source for moisture absorption. However, CBP temperatures did not increase above ambient in two additional barns managed in a similar nature. Compost temperatures above 55 °C promote sanitization, but temperatures between 45 and 55 °C maximize material degradation (Stentiford, 1996). Temperatures observed by Barberg et al. (2007a), Klaas et al. (2010), and in the current study did not reach the level necessary (55 to 65°C) for material sanitization. Producers should target temperatures between 45 and 55 °C because the CBP barn objective is to maintain a dry surface while reducing CBP size and the need for wood shavings. When temperatures drop to 35 to 40 °C, the microbial population is much more diverse and not as efficient at degrading CBP material (Stentiford, 1996).

Tests of significance of fixed effects and estimated coefficients for the model of 20.3 cm CBP depth temperature are expressed in Table 2.3 and 2.4, respectively. Stirring frequency, ambient temperature, and the quadratic and cubic transformation of stirring depth affected 20.3 cm depth CBP temperature (Table 2.3, $P \leq 0.05$). Compost bedded pack temperatures increased as ambient temperatures increased (Table 2.3, $P < 0.05$). A decreased temperature gradient between the CBP and air may reduce the amount of CBP
heat lost due to conduction and evaporative cooling. This may be a concern during cold winter weather. As air cools, the temperature gradient between the CBP and air increases, leading to CBP heat loss. Thus, entering winter weather with an active compost layer generating sufficient heat is imperative for compost success and moisture reduction. Additionally, adding curtains in cool weather may increase inside barn air temperature and reduce evaporative cooling.

Increasing stirring frequency each day increased 20.3 cm depth CBP temperature (Table 2.3, \( P < 0.01 \)) from a mean of 30.0 ± 2.7 °C with 1X/d stirring to 40.0 ± 1.9 °C with 2X/d stirring (Figure 2.2). By aerating the CBP more frequently, compacted areas receive more air allowing composting microbes to work more efficiently and effectively (NRAES, 1992). Milking typically occurs two times per day, which presents a convenient time to stir the CBP without cows occupying the CBP. Compost bedded pack aeration is relatively easy and not time consuming, only lasting 15 to 30 min (B Klingensfus, personal communication), but improves composting efficiency. Increasing stirring depth also increased CBP temperature (Table 2.3, \( P = 0.04 \)). Deep aeration allows compacted and deep areas to receive more air, increasing composting efficiency and depth (NRAES, 1992) and increasing CBP temperature from microbial heat. Compost bedded pack temperature increased as stirring depth increased, with CBP temperature peaking when stirring depth was between 15 and 20 cm, dipping when stirring depth was between 25 and 35 cm, and increasing for stirring depths between 35 and 40 cm. Compost performance improves with increased stirring frequency and depth.

**Moisture.** Mean CBP moisture content was 56.1 ± 12.4 %. The composting process operates optimally between 40 and 60% moisture content (Jeris and Regan, 1973,
Excessive moisture content may inhibit aerobic activity due to loss of interstitial integrity, or porosity (Golueke and Diaz, 1990, NRAES, 1992) and reduced surface area resulting from compacted material forming chunks. Higher moisture also increases the ease to which material can adhere to teat ends. Moisture content below 30 to 35% may also inhibit microbial activity, ceasing the composting process (NRAES, 1992, Stentiford, 1996) until additional moisture is added. These conditions are likely observed in the summer and, although active composting does not occur, the bedding material provides a dry surface for cows to lie on, which is one overall system goal.

Tests of significance of fixed effects and estimated coefficients for the model of CBP moisture are expressed in Table 2.5 and 2.6, respectively. Drying rate significantly affected CBP moisture (Table 2.5, \( P < 0.05 \)). Increasing drying rate reduced CBP moisture (\( P < 0.01 \)). Both ambient temperature and RH were uncontrollable by the producer; however, the producer can manipulate air velocity. Proper site selection is one way to increase air velocity. Building barns too close to other structures reduces natural ventilation. Chastain (2000) recommended a minimum of 22.9 m between buildings and a location on high ground to maximize natural ventilation. Mechanical ventilation using fans can also increase air velocity. Research (Brockett and Albright, 1987, Chastain, 2000, Snell et al., 2003) on fans focuses on the effect of ventilation rate and fan placement on the cow; however, no research has examined the effect of ventilation rate on CBP moisture. However, similar recommendations may be applicable. Fan number and placement depend on stocking density, ambient conditions, and barn use and construction (Wells, 1990) and cows should receive a minimum of 0.024 m\(^3\)/s airflow in
the winter, and 0.236 m$^3$/s airflow in the summer (Stowell and Bickert, 1995).

Composting performance improved with increased drying rate.

**Herd Health**

**Lameness.** Mean lameness score was 1.5 ± 0.9 (n = 1,719). Of all cows scored for lameness, 69.3% scored a 1, 18.7% scored a 2, 6.9% scored a 3, 4.4% scored a 4, and 0.6% scored a 5. Clinical lameness prevalence (locomotion score ≥ 3) was 11.9%, with 5% of cows scored as severely lame (locomotion score ≥ 4). A study conducted in Minnesota by Espejo et al. (2006) observed lameness prevalence of high-producing Holstein cows in freestall barns. Espejo reported 19.3% of cows scoring as 1, 56.1% as 2, 18.6% as 3, 5.8% as a 4, and 0.3% scoring a 5 (n = 5626), producing a mean locomotion score of 2.1 across all herds. The reduced locomotion score of cows housed in CBP barns during this study supports the concept that CBP barns assist in reducing lameness by providing a softer standing surface compared to freestall barns (Phillips and Schofield, 1994, Somers et al., 2003, Vaarst et al., 1998). Less time is spent standing on concrete flooring, which can reduce hoof disorders (Sogstad et al., 2005). Eckelkamp et al. (2013) reported that cows transitioning from an outdated freestall barn to a CBP barn spent 4 h/d more lying than in the freestall system (13.1 vs. 9.1 h/d, respectively). Further, lame cows (locomotion score ≥ 3 using scoring system by Sprecher et al. (1997)) spent 5 h/d more lying on the CBP compared to the freestall system (13.1 vs. 8.0 h/d, respectively, $P < 0.05$). Improper stall design can lead to reduced stall use and increased lameness incidence within the herd (Dippel et al., 2009). Recuperation from injury and improper facility design related disorders may be easier on the CBP because cows not using stalls due to improper stall design no longer had lying restrictions. Sound cows
(locomotion score ≤ 2) increased lying time by 3 h/d when transitioned from the freestall system to the CBP barn (10.1 vs. 13.1 h/d respectively, $P < 0.05$).

**Hygiene.** Proper cow hygiene management can reduce mastitis risk (Neave et al., 1969, Reneau et al., 2005, Schreiner and Ruegg, 2003). Conventional bedded pack systems are associated with poor cow cleanliness and increased mastitis risk (Berry, 1998, Peeler et al., 2000, Ward et al., 2002). In the current study, mean hygiene score was $2.2 \pm 0.7$ ($n = 1,699$). Of all cows scored for hygiene during the current study, 12.3% scored a 1, 57.9% scored a 2, 23.2% scored a 3, and 6.6% scored a 4. Nearly one-third of the cows scored were considered dirty (hygiene score ≥ 3). Barberg et al. (2007b) observed a mean hygiene score of 2.66 for the 12 CBP barns visited. Shane et al. (2010) observed a mean hygiene score of 3.10 for six CBP barns. A study comparing CBP barns, CV barns, and NV barns noted that cows housed in CBP barns had increased hygiene scores (3.18) compared with the CV (2.83) and NV (2.77) barns (Lobeck et al., 2011). Klaas et al. (2010) evaluated cow cleanliness in CBP barns in Israel, systems that do not add additional bedding material. Researchers determined 51.2% of cows scored as dirty (a score of 3 or 4). They noted that the farm with cleaner cows operated a barn with high CBP temperatures, but farms with dirtier cows did not generate high CBP temperatures. Researchers hypothesized that cow hygiene reflected compost performance. Operating CBP with high temperatures and efficient composting may lead to cleaner cows.

Tests of significance of fixed effects and estimated coefficients for the model of cow hygiene are expressed in Table 2.7 and 2.8, respectively. Ambient temperature, 20.3 cm depth CBP temperature, and the interaction between moisture and ambient
temperature significantly affected cow hygiene (Table 2.7, $P < 0.05$). Increasing 20.3 cm depth CBP temperature reduced hygiene scores (Table 2.8, $P < 0.01$). High CBP temperatures are a key management strategy for composting efficiency (Imbeah, 1998). Pathogen destruction, or sanitization, occurs when compost temperatures reach 55 to 65 °C; however, efficient compost material degradation occurs when temperatures are between 45 and 55 °C (Stentiford, 1996). Temperatures observed in the current study ($36.1 \pm 11.0 \, ^\circ\mathrm{C}$) would support minimal material degradation.

The interaction between moisture and ambient temperature significantly affected cow hygiene (Figure 2.3, $P < 0.01$). When moisture was low (35%, Jeris and Regan, 1973, Stentiford, 1996, Suler and Finstein, 1977) and ambient temperature was high, hygiene scores were reduced. However, when moisture was high (70%, Jeris and Regan, 1973, Stentiford, 1996, Suler and Finstein, 1977) and ambient temperature was high or low, hygiene scores were increased. The observed decrease is similar to the relationship observed by Lobeck et al. (2011) where hygiene score increased in the winter compared to the summer (3.33 vs. 3.21, respectively), though the difference was not significant ($P > 0.05$). Compost bedded pack moisture decreased with increased drying rate, which increased with high ambient temperatures. Therefore, higher ambient temperatures likely reduce CBP moisture, providing cows a drier surface to lie on with less material adhering to the cow when cows stand. Additionally, water-holding capacity of the air increases with higher ambient temperatures, allowing for more moisture evaporation from the CBP. Schreiner and Ruegg (2003) observed a 1.5-fold increase in mammary infection risk when hygiene scored a 3 or 4 compared to cows, which scored a 1 or 2. In all scenarios of the interaction of ambient temperature and moisture, hygiene score was maintained.
below a score of 3, indicating wide ranges in temperature and CBP performance can support improved cow hygiene. Management of CBP moisture is more important in colder temperatures because cow hygiene is likely more easily compromised due to the increased moisture conditions. Producers should maintain a dry resting surface for cows by either adding an appropriate amount of bedding to absorb moisture or allowing more space per cow to reduce the moisture inputted into the CBP.

**Historical SCC Data.** Mean BTSCC for farms using the CBP barn as primary housing (n = 9) decreased from the y before moving into the CBP barn to the y after (323,692 ± 7,301 vs. 252,859 ± 7,112 cells/mL, respectively; \( P < 0.01 \)). Norman et al. (2010) reported a mean DHIA SCC of 313,000 cells/mL in Kentucky demonstrating that SCC in CBP barns were lower than the mean Kentucky DHIA SCC. Summer season SCC were elevated compared to fall, spring, and winter (323,862 ± 10,502 vs. 288,329 ± 10,058, 272,752 ± 10,146, and 265,159 ± 10,058 cells/mL, respectively, \( P < 0.05 \)). No seasonal differences relative to compost barn construction were observed. Barkema et al (1998a) reported no correlation between SCC level and clinical mastitis incidence. Therefore, although milk quality may be acceptable, no assumptions can be made about clinical mastitis in herds housed on a CBP. Better housing environment management likely plays a role in the BTSCC decrease. For cows on unmanaged pasture or lots, providing housing, whether a CBP or freestall facility, typically improves the environment, which may improve overall cow health. Additionally, this transition calls for increased management skill and may improve the overall herd management. The herds that transitioned from a freestall barn typically transitioned from an outdated barn that needed renovations. The new CBP barn likely had improved ventilation, lying
surface, and overall management, which can affect overall animal health. However, this improvement is expected with any new housing facility.

Producers housing special needs cows in the CBP barn (n = 3) experienced no change in BTSCC from before to after moving into the CBP barn (292,146 ± 11,021 vs. 299,577 ± 11,258 cells/mL, respectively; \( P > 0.05 \)). Summer season SCC were higher compared to spring, fall, and winter (359,360 ± 14,760 vs. 302,516 ± 15,671, 279,240 ± 14,760, and 42,328 ± 17,439 cells/mL, respectively, \( P < 0.05 \); however, the winter season produced a lower SCC compared to spring \( (P < 0.05) \). Most cows in these herds were housed in freestall barns and the BTSCC is more impacted by the freestall environment and not the CBP barn environment. These changes in BTSCC are more likely attributed to changes in weather, management, or freestall housing conditions.

**DHIA Data.** Table 2.9 includes the mean herd performance metrics for the y before (12 mo before moving into the CBP barn), transition y (1 to 12 mo after moving into the CBP barn), and second y (13 to 24 mo after moving into the CBP barn) after moving into the CBP barn for producers using the CBP barn as a primary housing facility. Daily milk production increased from before moving into the CBP to the second y after barn occupation (29.3 ± 0.3 vs. 30.7 ± 0.3 kg, respectively; \( P < 0.05 \)). Rolling herd milk yield average increased from 8,937 ± 79 kg to 9,403 ± 74 kg. For herds transitioning from a pasture or lot, a production increase may be due to feed being closer and more accessible. In addition, feeding a TMR, or more DMI coming from the TMR, can increase milk production (Kolver and Muller, 1998). A decrease from 411,230 ± 20,209 to 275,510 ± 20,080 cells/mL occurred for SCC for the y before to the second y after CBP barn occupation. Norman et al. (2010) reported a mean DHIA SCC of 313,000
cells/mL in Kentucky demonstrating that SCC in CBP barns were lower than Kentucky DHIA SCC. However, proper management and procedures in the parlor are essential to maintaining udder health. Improvement in reproductive parameters from the y before to the second y after barn occupation occurred including calving interval (14.3 ± 0.1 vs. 13.7 ± 0.1 mo, respectively; \( P < 0.05 \)), d to first service (104.1 ± 3.0 vs. 85.3 ± 3.0 d, respectively; \( P < 0.05 \)), and d open (173.0 ± 3.5 vs. 153.4 ±3.4 d, respectively; \( P < 0.05 \)). An increase in the percent of heats observed occurred from the y before the y after barn occupation (42.0 ± 2.6 vs. 48.7 ± 2.5%, respectively; \( P < 0.05 \)). However, observed heats decreased from the first y of occupation to the second (48.7 ± 2.5 vs. 39.5 ± 2.5%, respectively; \( P < 0.05 \)). An increase in percent of heats observed may be explained by the softer CBP surface, which provides cows better footing for estrus behavior expression (Phillips and Schofield, 1994). In addition, with cows in closer proximity to the parlor, producers can observe estrus behavior more easily. Pregnancy rate and the conception rate remained unaltered after the transition (\( P > 0.05 \)). Changes in reproductive parameters can likely been attributed to changes in management. Moving a herd from pasture or a lot to a housing system requires a different management strategy and thus, may alter reproductive strategies and management.

Table 2.10 includes the mean herd performance metrics for the y before, transition y, and second y after moving into the CBP barn for producers using the CBP barn as a special needs housing facility. No significant changes occurred with daily milk production, rolling herd average milk production, SCC, calving interval, d to first service or pregnancy rate (\( P > 0.05 \)). In these cases, the CBP barn typically housed a small portion of the herd, producing little impact on overall herd performance. The CBP was
used more to improve feet and leg health of certain cows or reduce stresses caused by the freestall environment. This group of producers did experience an increase in the percent of successful breedings (34.3 ± 1.7 vs. 41.9 ± 1.7%; \( P < 0.05 \)) and a decrease in the percent of heats observed (53.4 ± 2.1 vs. 46.0 ± 2.1%; \( P < 0.05 \)) from the y before to the second y after barn occupation, respectively. However, these changes likely involve deviations in overall herd management and have little to do with the CBP barn due to the small portion of cows housed in this system.

**CONCLUSIONS**

Increased stirring depth and frequency, and increased space per cow increased CBP temperature, but increased stirring depth, space per cow and drying rate decreased CBP moisture. Managing the CBP for reduced moisture and increased temperature improved cow hygiene. Producer satisfaction, historical BTSCC (reduced BTSCC), and DHIA data (reduced SCC, improved reproduction performance, and reduced culling), support reported CBP barn system benefits. Producer observations and analysis of additional factors affecting compost performance will benefit existing and future adopters of the CBP barn system.

**ACKNOWLEDGEMENTS**

We would like to thank the participating producers for their cooperation in this study. We extend our gratitude to the University of Kentucky County Extension Agents and Kentucky Dairy Development Council consultants who assisted with the project and University of Kentucky Regulatory Services for their financial and laboratory assistance throughout the study. Additionally, we would like to thank Dr. Connie Wood and Ms.
Kristen McQuerry for their exceptional statistical support and Jessica Lowe, Alexis Thompson, Karmella Dolecheck, and Elizabeth Eckelkamp for paper review.
Table 2.1. Producer cited CBP benefits, recommended facility changes, and producer recommendations to other producers building a CBP barn from 43 CBP barn producers in Kentucky.

<table>
<thead>
<tr>
<th>Comment</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Producer cited CBP barn benefits</strong></td>
<td></td>
</tr>
<tr>
<td>Improved cow comfort</td>
<td>28</td>
</tr>
<tr>
<td>Improved cow cleanliness</td>
<td>14</td>
</tr>
<tr>
<td>Low maintenance system</td>
<td>10</td>
</tr>
<tr>
<td>Good for heifers, lame, fresh, problem, and old cows</td>
<td>10</td>
</tr>
<tr>
<td>Natural resting position (lack of stalls)</td>
<td>9</td>
</tr>
<tr>
<td>Improved feet and legs</td>
<td>8</td>
</tr>
<tr>
<td>Proximity to the parlor (compared to pasture)</td>
<td>8</td>
</tr>
<tr>
<td>Decreased SCC</td>
<td>6</td>
</tr>
<tr>
<td>Increased heat detection</td>
<td>6</td>
</tr>
<tr>
<td>Ease of manure handling</td>
<td>3</td>
</tr>
<tr>
<td>Increased DMI (compared to pasture)</td>
<td>3</td>
</tr>
<tr>
<td>Increased production</td>
<td>3</td>
</tr>
<tr>
<td>Increased longevity</td>
<td>3</td>
</tr>
<tr>
<td>Fewer leg and teat injuries</td>
<td>2</td>
</tr>
<tr>
<td>Minimizes time standing on concrete</td>
<td>2</td>
</tr>
<tr>
<td><strong>Recommended facility changes</strong></td>
<td></td>
</tr>
<tr>
<td>Increase size or capacity of the barn</td>
<td>15</td>
</tr>
<tr>
<td>Higher sidewalls and improved ventilation</td>
<td>12</td>
</tr>
</tbody>
</table>
Table 2.1. cont.

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Add retaining wall</td>
<td>6</td>
</tr>
<tr>
<td>Add curtains</td>
<td>5</td>
</tr>
<tr>
<td>More fans</td>
<td>5</td>
</tr>
<tr>
<td>Larger ridge vent</td>
<td>5</td>
</tr>
<tr>
<td>No posts in pack</td>
<td>4</td>
</tr>
<tr>
<td>Change number or location of waterers</td>
<td>4</td>
</tr>
<tr>
<td>Change location or size of feed alley</td>
<td>4</td>
</tr>
<tr>
<td>Length of overhang or eaves</td>
<td>3</td>
</tr>
<tr>
<td>Distance between pack and holding pen</td>
<td>2</td>
</tr>
<tr>
<td>No concrete base under pack</td>
<td>2</td>
</tr>
<tr>
<td>More entrances</td>
<td>2</td>
</tr>
<tr>
<td>Wider</td>
<td>2</td>
</tr>
</tbody>
</table>

Producer recommendations to other producers building a CBP barn

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secure a bedding supply</td>
<td>11</td>
</tr>
<tr>
<td>Stir pack two times per d or frequently</td>
<td>9</td>
</tr>
<tr>
<td>Use kiln-dried shavings</td>
<td>6</td>
</tr>
<tr>
<td>Do not use straw, wheat straw, corn fodder, bean fodder, or pine</td>
<td>6</td>
</tr>
<tr>
<td>Minimum of 9.29 m² per cow</td>
<td>5</td>
</tr>
<tr>
<td>Keep CBP maintained and moisture low</td>
<td>5</td>
</tr>
<tr>
<td>Build the barn large</td>
<td>4</td>
</tr>
<tr>
<td>Add bedding frequently</td>
<td>4</td>
</tr>
<tr>
<td>Designated tractor for stirring</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 2.1. cont.

<table>
<thead>
<tr>
<th>Item</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tour other barns</td>
<td>2</td>
</tr>
<tr>
<td>Add curtains</td>
<td>3</td>
</tr>
<tr>
<td>Do not start pack during winter</td>
<td>3</td>
</tr>
<tr>
<td>Build barn with the correct orientation</td>
<td>2</td>
</tr>
<tr>
<td>Need fine and coarse wood particles</td>
<td>2</td>
</tr>
<tr>
<td>Do not use green sawdust</td>
<td>2</td>
</tr>
<tr>
<td>Soy stubble can work in correct ratio</td>
<td>2</td>
</tr>
<tr>
<td>Long overhang</td>
<td>2</td>
</tr>
<tr>
<td>High sidewalls</td>
<td>2</td>
</tr>
<tr>
<td>Pay for better shavings</td>
<td>2</td>
</tr>
</tbody>
</table>
Table 2.2. Compost nutrient analysis values for collected compost samples of 47 compost bedded pack barns in Kentucky.

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>56.1%</td>
<td>12.4%</td>
<td>27.0%</td>
<td>70.0%</td>
</tr>
<tr>
<td>Carbon</td>
<td>41.8%</td>
<td>5.1%</td>
<td>20.9%</td>
<td>47.1%</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.7%</td>
<td>0.5%</td>
<td>1.0%</td>
<td>2.9%</td>
</tr>
<tr>
<td>C:N(^1)</td>
<td>26.7</td>
<td>7.8</td>
<td>11.3</td>
<td>43.2</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.4%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.9%</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.3%</td>
<td>0.5%</td>
<td>0.4%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Calcium</td>
<td>2.0%</td>
<td>3.2%</td>
<td>0.6%</td>
<td>22.3%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.5%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Zinc</td>
<td>110.4 ppm</td>
<td>45.9 ppm</td>
<td>36.5 ppm</td>
<td>217.9 ppm</td>
</tr>
<tr>
<td>Copper</td>
<td>27.8 ppm</td>
<td>15.5 ppm</td>
<td>7.8 ppm</td>
<td>61.9 ppm</td>
</tr>
<tr>
<td>Manganese</td>
<td>222.4 ppm</td>
<td>135.0 ppm</td>
<td>110.8 ppm</td>
<td>818.9 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>2779.7 ppm</td>
<td>2339.4 ppm</td>
<td>471.4 ppm</td>
<td>9077.7 ppm</td>
</tr>
</tbody>
</table>

\(^1\)C:N = carbon to nitrogen ratio. Calculated as carbon content (%) divided by nitrogen content (%).
Table 2.3. Tests of significance of fixed effects for mean 20.3 cm compost bedded pack depth temperature general linear model for 44 compost bedded pack barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator DF</th>
<th>Denominator DF</th>
<th>Type 3 SS F Value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature, °C</td>
<td>1</td>
<td>38</td>
<td>4.12</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Stirring frequency, times per d</td>
<td>1</td>
<td>38</td>
<td>8.19</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Stirring depth, cm</td>
<td>1</td>
<td>38</td>
<td>3.66</td>
<td>0.06</td>
</tr>
<tr>
<td>Stirring depth x stirring depth</td>
<td>1</td>
<td>38</td>
<td>4.01</td>
<td>0.05</td>
</tr>
<tr>
<td>Stirring depth x stirring depth x stirring depth</td>
<td>1</td>
<td>38</td>
<td>4.40</td>
<td>0.04</td>
</tr>
</tbody>
</table>

*\(R^2 = 0.316\)
Table 2.4. Estimated coefficients for model of mean 20.3 cm compost bedded pack depth temperature.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-29.4393</td>
<td>35.77</td>
<td>-0.82</td>
<td>0.42</td>
</tr>
<tr>
<td>Ambient temperature, ºC</td>
<td>0.3551</td>
<td>0.17</td>
<td>2.03</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Tilling Frequency, 1X/d</td>
<td>-9.9467</td>
<td>3.48</td>
<td>-2.86</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Tilling Frequency, 2X/d</td>
<td>0.0000</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>Tilling depth, cm</td>
<td>9.2410</td>
<td>4.83</td>
<td>1.91</td>
<td>0.06</td>
</tr>
<tr>
<td>Stirring depth x stirring depth</td>
<td>-0.4060</td>
<td>0.20</td>
<td>-2.00</td>
<td>0.05</td>
</tr>
<tr>
<td>Stirring depth x stirring depth x</td>
<td>0.0056</td>
<td>0.00</td>
<td>2.10</td>
<td>0.04</td>
</tr>
</tbody>
</table>


Table 2.5. Tests of significance of fixed effects for mean compost bedded pack moisture general linear model for 38 compost bedded pack barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator</th>
<th>Denominator</th>
<th>Type 3 SS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DF</td>
<td>DF</td>
<td>F Value</td>
</tr>
<tr>
<td>Stirring depth, cm</td>
<td>1</td>
<td>34</td>
<td>2.54</td>
</tr>
<tr>
<td>Pasture adjusted space per cow¹, m²/cow</td>
<td>1</td>
<td>34</td>
<td>2.09</td>
</tr>
<tr>
<td>Drying rate², kg H₂O/m² • s</td>
<td>1</td>
<td>34</td>
<td>37.43</td>
</tr>
</tbody>
</table>

*R² = 0.621

¹Space per cow calculated as total compost bedded pack area divided by total number of cows housed on compost bedded pack. Space per cow adjusted by dividing by 1 – percent time (expressed as a decimal) spent on pasture per d.

²Drying rate calculated
### Table 2.6. Estimated coefficients for model of CBP moisture.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>74.7190</td>
<td>4.27</td>
<td>17.49</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Stirring depth, cm</td>
<td>-0.2494</td>
<td>0.16</td>
<td>-1.59</td>
<td>0.12</td>
</tr>
<tr>
<td>Pasture adjusted space per cow(^1), m(^2)/cow</td>
<td>-0.2215</td>
<td>0.15</td>
<td>-1.44</td>
<td>0.16</td>
</tr>
<tr>
<td>Drying rate(^2), kg H(_2)O/m(^2) • s</td>
<td>-51.5479</td>
<td>8.43</td>
<td>-6.12</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

\(^1\)Space per cow calculated as total compost bedded pack area divided by total number of cows housed on compost bedded pack. Space per cow adjusted by dividing by 1 – percent time (expressed as a decimal) spent on pasture per d.

\(^2\)Drying rate calculated as
Table 2.7. Tests of significance of fixed effects for mean cow hygiene general linear model for 32 CBP barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator DF</th>
<th>Denominator DF</th>
<th>Type 3 SS</th>
<th>F Value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature, °C</td>
<td>1</td>
<td>27</td>
<td></td>
<td>9.61</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>20.3 cm depth pack temperature, °C</td>
<td>1</td>
<td>27</td>
<td></td>
<td>16.19</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Pack moisture, %</td>
<td>1</td>
<td>27</td>
<td></td>
<td>1.03</td>
<td>0.32</td>
</tr>
<tr>
<td>Ambient temperature x 20.3 cm depth pack temperature</td>
<td>1</td>
<td>27</td>
<td></td>
<td>8.20</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

*R² = 0.745
Table 2.8. Estimated coefficients for model of cow hygiene.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>3.9125</td>
<td>0.78</td>
<td>5.04</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature, °C</td>
<td>-0.1069</td>
<td>0.03</td>
<td>-3.10</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>20.3 cm depth pack temperature, °C</td>
<td>-0.0217</td>
<td>0.01</td>
<td>-4.02</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Pack moisture, %</td>
<td>-0.0108</td>
<td>0.01</td>
<td>-1.01</td>
<td>0.32</td>
</tr>
<tr>
<td>Ambient temperature x 20.3 cm depth</td>
<td>0.0017</td>
<td>0.00</td>
<td>2.86</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>
Table 2.9. Changes in production and reproductive parameters for eight farms\(^1\) enrolled in DHIA before and after moving in a compost bedded pack barn.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Before(^4)</th>
<th>Transition(^3)</th>
<th>After(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily milk production, kg</td>
<td>29.3 ± 0.3(^a)</td>
<td>30.1 ± 0.3(^{ab})</td>
<td>30.7 ± 0.3(^b)</td>
</tr>
<tr>
<td>Peak milk production, kg</td>
<td>38.7 ± 0.4(^a)</td>
<td>39.8 ± 0.3(^b)</td>
<td>40.0 ± 0.4(^b)</td>
</tr>
<tr>
<td>Standardized 150d milk production, kg</td>
<td>31.6 ± 0.3(^a)</td>
<td>32.1 ± 0.3(^{ab})</td>
<td>32.7 ± 0.3(^b)</td>
</tr>
<tr>
<td>Summit milk production, kg</td>
<td>35.5 ± 0.4(^a)</td>
<td>37.1 ± 0.4(^b)</td>
<td>37.1 ± 0.4(^b)</td>
</tr>
<tr>
<td>Rolling herd average milk production, kg</td>
<td>8,937 ± 79(^a)</td>
<td>9,194 ± 73(^b)</td>
<td>9,403 ± 74(^b)</td>
</tr>
<tr>
<td>Mature Equivalent 305d milk Production, kg</td>
<td>10,223 ± 77(^a)</td>
<td>10,503 ± 75(^b)</td>
<td>10,599 ± 77(^b)</td>
</tr>
<tr>
<td>SCC, cells/mL</td>
<td>411,230 (±20,209)^(^a)</td>
<td>305,410 ± (19,704)^(^b)</td>
<td>275,510 ± (20,080)^(^b)</td>
</tr>
<tr>
<td>Actual calving interval, mo</td>
<td>14.3 ± 0.1(^a)</td>
<td>14.2 ± 0.1(^b)</td>
<td>13.7 ± 0.1(^b)</td>
</tr>
<tr>
<td>Days to first service, d</td>
<td>104.1 ± 3.0(^a)</td>
<td>80.3 ± 3.1(^b)</td>
<td>85.3 ± 3.0(^b)</td>
</tr>
<tr>
<td>Days open, d</td>
<td>173.0 ± 3.5(^a)</td>
<td>153.9 ± 3.3(^b)</td>
<td>153.4 ± 3.4(^b)</td>
</tr>
<tr>
<td>Percent successful, %</td>
<td>38.4 ± 1.2</td>
<td>39.6 ± 1.3</td>
<td>38.2 ± 1.5</td>
</tr>
<tr>
<td>Percent heats observed, %</td>
<td>42.0 ± 2.6(^{ab})</td>
<td>48.7 ± 2.5(^a)</td>
<td>39.5 ± 2.5(^b)</td>
</tr>
<tr>
<td>Pregnancy rate, %</td>
<td>15.4 ± 1.9</td>
<td>13.9 ± 1.8</td>
<td>13.3 ± 1.7</td>
</tr>
</tbody>
</table>

\(^1\)All farms included used the compost bedded pack barn as a primary housing facility.

\(^2\)Different superscripts within a row denote a significant difference (\(P<0.05\)).
Table 2.9. cont.

3 Before represents the 12 m before moving into the compost bedded pack barn.

4 Transition represents the 12 m after moving into the compost bedded pack barn.

5 After represents the 13 to 24 m after moving into the compost bedded pack barn.
Table 2.10. Changes in production and reproductive parameters for seven farms\(^1\) enrolled in DHIA before and after moving in a compost bedded pack barn.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time Period(^2)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before(^3)</td>
<td>Transition(^4)</td>
<td>After(^5)</td>
</tr>
<tr>
<td>Daily milk production, kg</td>
<td>28.1 ± 0.5</td>
<td>29.1 ± 0.5</td>
<td>29.2 ± 0.5</td>
</tr>
<tr>
<td>Peak milk production, kg</td>
<td>37.6 ± 0.5</td>
<td>37.5 ± 0.5</td>
<td>38.0 ± 0.6</td>
</tr>
<tr>
<td>Standardized 150d milk production, kg</td>
<td>30.3 ± 0.6</td>
<td>32.7 ± 0.6</td>
<td>31.6 ± 0.6</td>
</tr>
<tr>
<td>Summit milk production, kg</td>
<td>35.2 ± 0.5</td>
<td>35.0 ± 0.5</td>
<td>35.5 ± 0.5</td>
</tr>
<tr>
<td>Rolling herd average milk production, kg</td>
<td>8,965 ± 160</td>
<td>9,074 ± 158</td>
<td>9,152 ± 161</td>
</tr>
<tr>
<td>Mature Equivalent 305d milk production, kg</td>
<td>9,808 ± 150</td>
<td>10,006 ± 148</td>
<td>10,069 ± 151</td>
</tr>
<tr>
<td>SCC, cells/mL</td>
<td>296,780 ± 13,576</td>
<td>276,420 ± 13,309</td>
<td>264,050 ± 13,576</td>
</tr>
<tr>
<td>Actual calving interval, mo</td>
<td>14.2 ± 0.1</td>
<td>14.3 ± 0.1</td>
<td>14.3 ± 0.1</td>
</tr>
<tr>
<td>Days to first service, d</td>
<td>91.7 ± 1.6</td>
<td>93.2 ± 1.5</td>
<td>94.1 ± 1.6</td>
</tr>
<tr>
<td>Days open, d</td>
<td>174.8 ± 3.2(^a)</td>
<td>164.9 ± 3.2(^b)</td>
<td>162.6 ± 3.2(^b)</td>
</tr>
<tr>
<td>Percent successful, %</td>
<td>34.3 ± 1.7(^a)</td>
<td>39.1 ± 1.6(^ab)</td>
<td>41.9 ± 1.7(^b)</td>
</tr>
<tr>
<td>Percent heats observed, %</td>
<td>53.4 ± 2.1(^a)</td>
<td>46.0 ± 2.1(^b)</td>
<td>46.0 ± 2.1(^b)</td>
</tr>
<tr>
<td>Pregnancy rate, %</td>
<td>12.5 ± 1.3</td>
<td>12.0 ± 1.0</td>
<td>13.2 ± 1.0</td>
</tr>
</tbody>
</table>

\(^1\)All farms included used the compost bedded pack barn as a special needs housing facility.
Table 2.10. cont.

Different superscripts within a row denote a significant difference ($P<0.05$).

Before represents the 12 mo before moving into the compost bedded pack barn.

Transition represents the 12 mo after moving into the compost bedded pack barn.

After represents the 13 to 24 mo after moving into the compost bedded pack barn.
Figure 2.1. Sampling locations used to collect bedding material for bacterial and nutrient analyses. Points A1 through A9 indicated estimated distribution of sampling locations in each compost bedded pack barn visited.
Figure 2.2. Least squares means of compost bedded pack 20.3 cm depth temperature when stirring frequency equals one or two times per day on 44 compost bedded pack barns in Kentucky.

Bars with different letters are significantly different.
Figure 2.3. Predicted regression of cow hygiene when ambient temperature and 20.3 cm depth compost bedded pack temperature varied on 32 compost bedded pack barns in Kentucky.

*\( P < 0.05 \)
CHAPTER THREE

The relationship between compost bedded pack performance and management and bacterial concentrations


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†Department of Biosystems and Agricultural Engineering,
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INTRODUCTION

Virginia dairy farmers developed the compost bedded pack (CBP) barn concept to improve cow comfort, increase cow longevity, and reduce initial barn costs (Wagner, 2002) while potentially reducing the mastitis risks associated with the conventional bedded pack. Producers used the bedded pack system layout and incorporated composting methods. Compost bedded pack barns provide an open resting area free of stalls or partitions (Janni et al., 2007). Producers use fine wood shavings or sawdust as bedding (Janni et al., 2007). A cultivator or rototiller incorporates manure, urine, and air into the CBP typically during milking two or three times per d (Barberg et al., 2007a, Janni et al., 2007, Shane et al., 2010). Aeration increases metabolic heat production by aerobic microbes and bacteria (Suler and Finstein, 1977). Higher temperatures (55 to 65 °C) promote pathogen destruction (Stentiford, 1996) which may be advantageous for mastitis-causing bacteria destruction. However, temperatures observed by Barberg et al. (2007a), Klaas et al. (2010), and Black et al. (2013) did not reach the level necessary for bedding sanitization. The lack of material sanitization during the microbial processes in the CBP indicates the system is more of a “semi-composting” system that does not fully cycle through the entire composting process. Higher temperatures also increase moisture evaporation (NRAES, 1992). Manure, urine, and microbial activity moisture act as moisture sources in a CBP (Janni et al., 2007). The CBP should remain between 50 to 60% moisture for efficient composting (Gray et al., 1971b, NRAES, 1992, Suler and Finstein, 1977).

Compost bedded pack barns do not have stalls or partitions and cows are allotted a given amount of space per cow. Wagner (2002) originally recommended 9.4 m²/cow.
for CBP barns. However, to accommodate cow manure and urine output, Janni et al. (2007) recommended 7.4 m²/cow for a 540 kg Holstein cow or 6.0 m²/cow for a 410 kg Jersey cow. Overstocking the CBP barn may result in increased bedding needs or dirty cows. Proper cow hygiene management can reduce mastitis risk (Neave et al., 1969, Philpot, 1979, Reneau et al., 2005, Schreiner and Ruegg, 2003). Barberg et al. (2007b) observed a mean hygiene score of 2.66 (Reneau et al., 2005, where 1 = clean and 5 = very dirty) for the 12 CBP barns visited while Shane et al. (2010) observed a mean hygiene score of 3.1 (Reneau et al., 2005, where 1 = clean and 5 = very dirty) for six CBP barns. A study comparing CBP barns, cross-ventilated (CV) barns, and naturally ventilated (NV) barns noted that cows housed in CBP barns had increased ($P < 0.05$) hygiene scores (3.18; Reneau et al., 2005, where 1 = clean and 5 = very dirty) compared with the CV (2.83) and NV (2.77) barns (Lobeck et al., 2011). Udder health, indicated by SCC, improved after moving into the CBP barn in a study by Barberg et al. (2007b), where mastitis infection rate (cows with SCC $\geq$ 200,000 cells/mL) decreased from 35.4% to 27.7%. Klaas et al. (2010) observed SCC of 133,000 cells/mL, 214,000 cells/mL, and 229,000 cells/mL for the three barns in Israel operating CBP barns without additional bedding added.

A direct correlation exists between the bacteria load at the teat end and mastitis incidence (Neave et al., 1966). Bedding contributes to teat end bacterial load (Hogan and Smith, 1997, Hogan et al., 1989, Zdanowicz et al., 2004) and minimizing bedding bacterial counts is an important management strategy. Janni et al. (2007) recommended avoiding green or wet (from uncured wood) sawdust or shavings because of possible increased teat end exposure to *Klebsiella* bacteria (Bagley et al., 1978, Fairchild et al.,
1982, Newman and Kowalski, 1973). Inorganic bedding, such as sand or crushed limestone, typically reduces bacteria concentrations within bedding material compared to organic bedding materials (Fairchild et al., 1982, Hogan et al., 1989, LeJeune and Kauffman, 2005, Zdanowicz et al., 2004). However, composting microbes and bacteria require a carbon source to proliferate, making inorganic bedding an impractical choice for use in CBP barns. A wide bacteria concentration range for coliforms (15.8 log\textsubscript{10} cfu/g, Fairchild et al., 1982; 6.2 log\textsubscript{10} cfu/g, Hogan et al., 1989; 17.8 log\textsubscript{10} cfu/g, Rendos et al., 1975), \textit{Klebsiella} (15.0 log\textsubscript{10} cfu/g, Fairchild et al., 1982; 4.8 log\textsubscript{10} cfu/g, Hogan et al. 1989, 15.3 log\textsubscript{10} cfu/g, Rendos et al., 1975), and Streptococcal species (7.1 log\textsubscript{10} cfu/g, Hogan et al., 1989; 16.2 log\textsubscript{10} cfu/g, Rendos et al., 1975) in sawdust bedding have been reported in bedding used in dairy barns. Chopped straw contained similar concentrations of coliforms (7.1 log\textsubscript{10} cfu/g), \textit{Klebsiella} (6.3 log\textsubscript{10} cfu/g), and Streptococcal species (7.8 log\textsubscript{10} cfu/g) compared to sawdust (Hogan et al., 1989). The high bacteria level in organic bedding makes it imperative to manage teat end cleanliness.

A Minnesota study by Barberg et al. (2007a) reported a total bacteria concentration of 16.0 log\textsubscript{10} cfu/g in 12 CBP barns, a content higher than the 13.8 log\textsubscript{10} cfu/g expected to increase risk for clinical mastitis (Jasper, 1980). Lobeck et al. (2012) determined that bedding in CBP, CV, and NV barns exhibited no difference ($P > 0.05$) in coliform, \textit{Klebsiella}, environmental \textit{Streptococcus}, or \textit{Staphylococcus} species. However, CBP barns contained higher ($P < 0.05$) \textit{Bacillus} levels (798,000 cfu/g) in the summer than NV (366,000 cfu/g) and CV barns (59,000 cfu/g) and lower \textit{Bacillus} levels (800 cfu/g) in the winter than NV barns (9,881,000 cfu/g). Bulk tank milk contained similar levels of \textit{Staphylococcus aureus}, non-ag \textit{Streptococcus}, \textit{Staphylococcus} species, and
coliforms for the three housing systems. The objectives of this study were to define bacteria populations within the CBP barn system and evaluate management strategies for reducing CBP bacteria levels.

**MATERIALS AND METHODS**

A field survey of 47 aerated compost bedded pack (CBP) barns was conducted in Kentucky between October 2010 and March 2011. Of the 47 barns, 34 barns were used as the primary housing facility for lactating cows. The remaining 13 barns were used as supplemental housing for special needs cows, i.e. lame, old, and sick cows. A companion paper describes herd characteristics, management practices, producer perception of the CBP system, compost characteristics including CBP temperature, moisture, and nutrient values, and herd performance including lameness, hygiene, and production and reproductive performance (Black et al., 2013). Damasceno (2012) described structure characteristics for these barns including building material, dimensions, and layout. Compost characteristics including physical, bacterial, chemical, and thermal properties observed in this study were also described (Damasceno, 2012).

**Bedding Material Bacterial Count Analysis**

Bedding material samples were collected during a single site visit from nine evenly distributed locations throughout each barn (Figure 3.1). Researchers collected 118.3 cm$^3$ of surface layer bedding material from each location (total 1,064.7 cm$^3$) using a 59.1 cm$^3$ measuring cup (Everyday Living™, The Kroger Co., Cincinnati, OH) in a 3.8 L plastic bag (Ziploc®, Slider Storage and Freezer Bags with SmartZip® Seal, Racine, WI) and thoroughly mixed the material to create a composite sample representative of the entire CBP. Samples were stored in a -40 ºC freezer until at least 20 composite samples
were collected and available for analysis. Sample preparation consisted of diluting material by mixing 25 g of bedding material with 225 g of 0.1% peptone solution to a 1:10 dilution. The mixture was hand mixed until the bedding material was well-suspended within the peptone solution. Further serial dilutions were performed to obtain countable plates. To determine total coliform species and *Escherichia coli* count, researchers added 1 mL of the appropriate dilution to 3M™ Petrifilm™ E. Coli/Coliform Count Plates (3M™ Microbiology Products, St. Paul, MN), and incubated the plates at 35 °C for 24 h. Colony forming units (cfu) were counted manually, obtaining both a coliform and *E. coli* count. Researchers determined streptococcal species count using TKT agar prepared in the lab and spiral plating (Eddy Jet, IUL Instruments, I.L.S., Leerdam, The Netherlands) the diluted material onto the plate. Plates were incubated 48 h at 35 °C. For Staphylococcal species, BBL™ Columbia CNA Agar (Becton, Dickinson and Company, Franklin Lakes, NJ) was prepared according to manufacturer directions. The diluted material was spread across the plate surface. Plates were incubated 48 h at 35 °C and then flooded with peroxide. Catalase positive colonies were counted as Staphylococcal species. Bacillus species counts were ascertained using Difco™ MYP Agar Mannitol-Egg Yolk Polymyxin B (Becton, Dickinson and Company, Franklin Lakes, NJ) prepared according to the manufacturer directions, and spiral plating (Eddy Jet, IUL Instruments, I.L.S., Leerdam, The Netherlands) the diluted material onto the plate. Incubation of CNA, TKT, and MYP plates occurred at 35 °C for 48 h, with cfu counted automatically using a colony counter (Flash & Go, IUL Instruments, I.K.S., Leerdam, The Netherlands). All bacteria counts are reported in $\log_{10} \text{cfu/g}$ on a wet matter basis.
**Compost Bed Conditions**

The same nine evenly distributed locations throughout the barn were used to collect bed temperatures (Figure 3.1). Compost bedded pack temperatures were collected 10.2 and 20.3 cm deep using a thermocouple-based thermometer (0.22 m length, accuracy of ± 2.2°C; Fluke Inc., model 87, Everett, WA, USA). The mean of the surface and 10.2 cm depth CBP temperatures was calculated to produce a composite temperature (CT). Compost bedded pack surface temperatures were collected using an infrared thermometer (accuracy of ±1°C; Fluke®, model 62, Everett, WA, USA). Ambient temperature was collected using a weather meter (accuracy of ±1°C; Kestrel®, model 4000, Sylvan Lake, MI, USA). Researchers collected 118.3 cm³ of surface layer bedding material from each location (a total amount of 1,064.7 cm³) using a 59.1 cm³ measuring cup (Everyday Living™, The Kroger Co., Cincinnati, OH) in a 3.8 L plastic bag (Ziploc®, Slider Storage and Freezer Bags with SmartZip® Seal, Racine, WI) and thoroughly mixed the material to create a composite sample representative of the entire CBP. Bedding material nutrient analyses were performed by University of Kentucky Regulatory Services laboratory personnel on all bedding material samples to determine moisture, P, K, Ca, Mg, Zn, Cu, Mn, and Fe concentrations by methods specified by Peters et al. (2003). The carbon to nitrogen ratio (C:N) was calculated for all barns. Space per cow was calculated by dividing the total pack area (not including feeding space) by the total number of lactating cows housed on the CBP.

**Statistical Analysis**

Variable selection criteria to describe bacteria concentration included CBP and management characteristics with a correlation (r > 0.3, P < 0.05) with at least one
bacteria species by using the CORR procedure of SAS® (Cary, NC) (Table 3.1). Variables tested included space per cow, CT, moisture, C:N, ambient temperature, stirring frequency, stirring depth, bedding addition amount, and time spent on pasture. Explanatory variables used to describe each bacteria count included moisture, CT, ambient temperature, C:N, and space per cow. Bacteria counts were transformed using a natural log transformation to produce normally distributed values. The GLM procedure of SAS® (Cary, NC) generated models to describe factors affecting bacteria counts using the explanatory variables selected using the CORR procedure described above. All models tested the same explanatory variables for each bacteria species to produce consistent models. Explanatory variable quadratic and cubic transformations were tested for all explanatory variables ($P < 0.05$) and all two- and three-way interactions between explanatory variables and significant transformations were tested ($P < 0.05$) using backward elimination and Type I sums of squares.

**RESULTS AND DISCUSSION**

**Bedding Material Bacterial Count**

Bacteria counts were $14.03 \pm 1.28 \log_{10} \text{cfu/g}$, $13.26 \pm 1.42 \log_{10} \text{cfu/g}$, $16.09 \pm 1.62 \log_{10} \text{cfu/g}$, $17.51 \pm 1.09 \log_{10} \text{cfu/g}$, and $16.82 \pm 1.26 \log_{10} \text{cfu/g}$ for coliform, *E. coli*, Streptococcal species, Staphylococcal species, and Bacillus species, respectively (Table 3.2). Of the total bacteria sampled, these species comprised 1.86%, 20.61%, 52.28%, and 25.25% for coliform, Streptococcal species, Staphylococcal species, and Bacillus species, respectively. Barberg et al. (2007a) observed lower bacteria levels compared to the present study, with total bacterial count equaling $16.03 \pm 15.64 \log_{10} \text{cfu/g}$. Additionally, Barberg et al. (2007a) noted different bacteria count proportions of
10.7% for coliforms, 39.4% for environmental Streptococcal species, 17.4% for environmental Staphylococcal species, and 32.5% for Bacillus species. Lobeck et al. (2012) also observed lower counts of $8.70 \log_{10} \text{cfu/g}$ for coliforms, $15.2 \log_{10} \text{cfu/g}$ for Streptococcal species, $7.6 \log_{10} \text{cfu/g}$ for Staphylococcal species, and $12.19 \log_{10} \text{cfu/g}$ for Bacillus species. These differences are not thoroughly understood but may be due to differences in environment between Kentucky and Minnesota, management practices, or bedding materials. Additionally, bacteria analyses in the current study included different sampling techniques for all bacteria sampled and different agars for coliform and Staphylococcal species. Time relative to pack stirring may also have also influenced differences due to reintegration of surface layer material into the warmer, deep layers of the CBP and deep, warmer layers exposed on the surface after stirring. In the current study, producers typically stirred the CBP before milking 2X per d. Site visits were conducted during the morning, evening, and night and did not account for this variable. Additionally, the study by Barberg et al. (2007a) did not indicate time relative to stirring when taking bedding samples.

A direct correlation exists between bacteria counts in bedding and bacteria counts on the teat ends (Hogan and Smith, 1997, Zdanowicz et al., 2004) and clinical mastitis rates (Hogan et al., 1989). Bedding containing greater than $10^6 \text{ cfu/g}$ total bacteria increased intramammary infection risk (Jasper, 1980). Hogan et al. (1999a, 1997, 2007) determined reduced bacteria concentration of coliform, Klebsiella, and streptococcal species in sawdust and recycled manure bedding up to one d after treatment with commercial conditioners compared to untreated sawdust and recycled manure; however, bacteria counts did not differ between the two groups on d 2 and 6. They explained that
the conditioner’s short efficacy rate might be due to continual bedding contamination from manure when cows enter freestalls, conditioner and bedding removal as cows exit the freestalls, and a buffering effect by the bedding on the conditioner. Bacteria proliferate more easily in organic bedding (Gram-negative: 7.1 cfu log_{10}/mL; Coliform: 6.2 cfu log_{10}/mL; Klebsiella species: 4.3 cfu log_{10}/mL; Streptococcal species: 7.5 cfu log_{10}/mL) compared to inorganic bedding (Gram-negative: 6.41 cfu log_{10}/mL; Coliform: 5.7 cfu log_{10}/mL; Klebsiella species: 3.4 cfu log_{10}/mL; Streptococcal species: 6.8 cfu log_{10}/mL) because organic bedding can supply nutrients, temperature and moisture for bacteria sustenance (Hogan et al., 1989). Zdanowicz et al. (2004) observed higher coliform and Klebsiella concentration and lower Streptococcal species concentration on teat ends of cows housed with sawdust bedding compared to sand bedding.

Managing the bed surface is important for udder health management. This may be achieved in several ways. Sustaining bed temperatures above 34 °C in the deeper CBP layers and below 15 °C at the surface CBP layer inhibits the proliferation and growth of E. coli, Streptococcus uberis (Ward et al., 2002), and other pathogens (Misra et al., 2003). Additionally, maintaining clean, dry udders reduces intramammary infection risk (Neave et al., 1969). Drier CBP surface layers resulted in cleaner cow legs and udders (Black et al., 2013), accomplished through a high drying rate, deep CBP stirring, and adequate space per cow. In this study, high bacteria levels were observed in the bedding material; however, SCC (252,860 cells/mL) remained under the state average for Kentucky (313,000 cells/mL, Norman et al., 2010). Therefore, producers should aim to maintain a dry surface for cows to lie on to reduce the risk of dirty cows and increased SCC. Producers did not report clinical mastitis rates within the herds, which may
increase or decrease when housed on the CBP. Clinical mastitis incidence and SCC monitor different udder health aspects (Pösö and Mäntysaari, 1996) and have little to no relationship (Barkema et al., 1998b). In the current study, though the SCC was less than the reported state average, clinical mastitis incidence may have increased or decreased by housing cows on the CBP. More research on this subject is necessary.

*Coliforms*

Tests of significance and estimated coefficients for the coliform model are depicted in Table 3.3 and 3.4, respectively. Coliform concentration was not affected by the explanatory variables ($P > 0.05$, Table 3.3), indicating that managing the CBP for optimal temperature, moisture, C:N, and space per cow to achieve successful composting may not alter total coliform concentration within the bedding material. However, the lack of a relationship may be related to the wide variation between farms or because the present study is a field survey and not a controlled study. Coliforms are gram-negative bacteria and environmental mastitis pathogens (Hogan et al., 1999b). Additionally, coliforms are associated with the intestinal tract, and are likely in high concentration because the CBP system uses manure as a substrate for composting. Potential coliform pathogens causing mastitis include *E. coli*, *Klebsiella*, and *Enterobacter* (Eberhart, 1984). The composting process requires an available organic carbon source; however, organic bedding materials expose cows to more gram-negative bacteria than cows exposed to an inorganic bedding material (Hogan et al., 1989). Additionally, using fresh or green sawdust (Bagley et al., 1978, Newman and Kowalski, 1973) can increase *Klebsiella pneumoniae* mastitis incidence. Current recommendations (Janni et al., 2007) suggest
bedding with sawdust or wood shavings possibly increases the likelihood of exposure to *Klebsiella* pathogens.

Other management practices should be employed to help minimize exposure or risk because CBP management through monitoring of moisture, temperature, C:N, and space per cow may not be an effective means of reducing coliform bacteria exposure to the udder. Erskine (1995) explained that environmental mastitis control is difficult because of confinement housing use and increased milk and manure production. Erskine recommended close attention be paid to dry cow housing and maternity pens. Coliform mastitis infection rate is highest in the first two wk of the dry period, the two wk before calving, and in early lactation (Smith et al., 1987). Coliform mastitis vaccines can reduce clinical mastitis incidence caused by coliform bacteria (González et al., 1989, Hogan et al., 1995). Using a germicidal teat sanitizer before milking can decrease the new intramammary infection rate caused by coliform mastitis (Pankey, 1989).

*Escherichia coli*

Tests of significance and estimated coefficients for the *Escherichia coli* model are depicted in Table 3.5 and 3.6, respectively. Significant explanatory variables for *E. coli* concentration included C:N and (C:N)^2 (P < 0.05, Table 3.5). *Escherichia coli* reached a peak of concentration when C:N was between 30:1 and 35:1, similar to the optimal composting range of 25:1 to 35:1 (Gray et al., 1971b, NRAES, 1992). This indicates that the optimal environment meeting the carbon and nitrogen demands of *E. coli* may be the same as that for composting.

*Escherichia coli* are Gram-negative coliform bacteria with a rod shape (Dufour, 1977). *Escherichia coli* resides in normal gut flora and is a facultative anaerobic species
continually excreted in the feces (Lehtolainen, 2004). Many of the strains living in the normal flora are non-pathogenic; however, some mastitic strains can be found in the intestinal flora (Linton and Robinson, 1984). Because of this, the CBP will contain *E. coli* because manure is a substrate in the system, and some of those bacteria will be mastitic pathogens. Ward et al. (2002) explained that *E. coli* are affected by three temperature ranges: the bacteria will survive with minimal multiplication in temperatures below 15 ºC, survive and multiply optimally between 15 and 45 ºC, and begin to die in temperatures above 45 ºC. In the current study, CBP temperature did not play a role in *E. coli* bacteria concentration; however, 45 ºC was not within the CT range modeled, meaning the CBP surface never reached temperatures high enough to destroy *E. coli* bacteria. Had CBP CT reached this level, composting would have reached the temperature necessary for optimal biodegradation (Stentiford, 1996); however, the CBP surface may have been too hot for cows to lie on. When the lying surface is hotter than that of the cow, heat is conducted towards the cow, raising the body temperature. When ambient conditions are warm, this additional heat conductance may prompt cows to stand instead of lying down. Managing the lower CBP layers for optimal composting may be a better management strategy than trying to achieve the high temperatures needed to destroy *E. coli* bacteria on the surface because of the effects on the cow.

**Staphylococcal Species**

Tests of significance and estimated coefficients for the Staphylococcus species model are depicted in Table 3.7 and 3.8, respectively. Ambient temperature significantly affected Staphylococcal species (*P* < 0.05, Table 3.7) indicating Staphylococcus species exhibit some heat intolerance. Staphylococcal species concentration increased as
ambient temperature increased \( (P < 0.05) \). *Staphylococcus aureus* survives in temperatures between 6 and 48 °C, with an optimum temperature of 37 °C (Vandenbosch et al., 1973). The wide temperature survival range combined with the additional CBP heat generation indicated Staphylococcal species may survive well in many climatic conditions. However, CBP temperature, moisture, C:N, and space per cow had no significant effect on Staphylococcal species concentration. Consistent CBP management for optimal moisture, temperature, C:N, and space per cow to achieve successful composting conditions may not influence the total Staphylococcal species concentration in the bedding material. Staphylococcal species concentration may increase in winter weather because of the increased survival in lower ambient temperatures. Producers should concentrate on preventative mastitis methods, such as proper milking procedures and dry-off treatment.

Staphylococcal species are gram-positive bacteria with a cocci shape, forming clusters (Chauhan et al., 2012). As with other bacteria, some species are harmless while others can cause disease. *Staphylococcus aureus* is a contagious mastitis cause in dairy herds (Barkema et al., 2006). Bedding can be a *S. aureus* source (Roberson et al., 1994), but replacement heifers (Roberson et al., 1994) and milking equipment (Zadoks et al., 2002) likely contribute more to the spread. Coagulase negative staphylococci (CNS) are usually considered a minor mastitis pathogen because mastitis cases are typically mild and subclinical (Taponen et al., 2006); however, CNS mastitis has become the most common mastitis type in many countries (Pitkälä et al., 2004, Tenhagen et al., 2006). Some CNS species may be environmental opportunists, but most CNS species causing intramammary infection reside on the udder (Pyörälä and Taponen, 2009). When dealing
with a *Staphylococcal aureus* or CNS mastitis outbreak, improved management within the parlor, at dry off, and during calving should be considered.

**Streptococcal Species**

Tests of significance and estimated coefficients for the Streptococcus species model are depicted in Table 3.9 and 3.10, respectively. Several explanatory variables significantly influenced Streptococcal species concentration ($P < 0.05$, Table 3.9) within the CBP including: space per cow, CT, C:N, ambient temperature, $(C:N)^2$, and the interactions between moisture and C:N, moisture and space per cow, moisture and ambient temperature, ambient temperature and space per cow, CT and C:N, moisture, space per cow, and ambient temperature, and moisture and $(C:N)^2$. Streptococcal species grow in temperatures between 25 and 42 ºC (Hardie and Whiley, 1995). Achieving CBP temperatures greater than 42 ºC may reduce Staphylococcal species concentrations. This management practice can also help reduce pack moisture by increasing moisture evaporation from the pack by increased temperature and moisture addition reduction from manure and urine input.

Streptococcal species concentration peaked when C:N ranged from 16:1 to 18:1 ($P < 0.05$), a range slightly lower than that which is ideal from composting (Gray et al., 1971b, NRAES, 1992). This result indicates that Streptococcal species may thrive in a carbon concentration environment similar to that of composting microbes. Though individual management strategies, such as managing space per cow, CBP temperature, and C:N, can affect the Streptococcal species concentration within the CBP, better management is achieved by managing the CBP as a system of interactions. Streptococcal species reduction occurred in low moisture and high C:N conditions (Figure 3.2) ($P <$
However, a peak in Streptococcal species occurred in low moisture conditions with a C:N between 20:1 and 22:1 ($P < 0.05$). This illustrates that prevalence of Streptococcal species can differ based on C:N within the same moisture state, demonstrating the importance of managing C:N and moisture concurrently. Figure 3.3 displays the interaction of C:N and CT ($P < 0.05$). Similar to the interaction between C:N and moisture, a peak in Streptococcal species concentration occurred when C:N was between 16 and 18. However, when C:N was low, Streptococcal species concentration decreased with increasing CT. When C:N was high, Streptococcal species increased with increasing CT.

The three-way interaction between space per cow, moisture, and ambient temperature affected Streptococcal species concentration ($P < 0.05$). In low moisture conditions (Figure 3.4), Streptococcal species concentration decreased with increased space per cow and decreased ambient temperature ($P < 0.05$). In high moisture conditions (Figure 3.5), Streptococcal species increased with increasing stocking density and increased ambient temperature ($P < 0.05$); however, the increase was less influenced by space per cow and ambient temperature in high moisture conditions than in low moisture conditions. Ambient conditions cannot be controlled; therefore, producers should manage for low moisture conditions that still meet composting water requirements (45 – 65% moisture) and high space per cow.

Streptococcus species are gram-positive, spherical shaped bacteria, which grow in chains. *Streptococcus uberis* resides on many cow body sites (Cullen, 1966, Cullen and Little, 1969, Kruze and Bramley, 1982) and in the environment, including the bedding (Bramley, 1982). *Streptococcus agalactiae* are contagious mastitis pathogens, but are
susceptible to penicillin therapy and can be eradicated from a herd (McDonald, 1977). Though the initial Streptococcal species population is usually lower in inorganic bedding than organic bedding (Bramley and Dodd, 1984), concentrations increase in inorganic bedding as the lying area is contaminated with manure and urine (Hogan et al., 1989). Additionally, wood-based bedding materials contain lower Streptococcal species concentrations than straw (Bramley, 1982, Rendos et al., 1975). The current recommendation of sawdust or wood shavings (Janni et al., 2007) over straw as a bedding source in the CBP may be beneficial in reducing Streptococcal species numbers.

These results imply Streptococcal species thrive in the environment ideal for composting bacteria and microbes. Considering this, an ideal management strategy for Streptococcal species concentration reduction may be to provide adequate space per cow in winter weather, while being careful to maintain recommended moisture levels (50 to 60%; Gray et al., 1971b, NRAES, 1992). If Streptococcal species mastitis infections begin to elevate within the herd, a management strategy may be to cease composting to reduce pack temperatures and allow the cows to lie on an extremely dry, carbon-rich surface.

Bacillus Species

Tests of significance and estimated coefficients for the Bacillus species model are depicted in Table 3.11 and 3.12, respectively. Explanatory variables significantly influencing Bacillus species concentration ($P < 0.05$, Table 3.11) included ambient temperature, space per cow, moisture, C:N, and CT. Significant interactions in the model included ambient temperature and space per cow, ambient temperature and moisture,
ambient temperature and C:N, moisture and C:N, moisture and space per cow, ambient temperature, moisture, and space per cow, and ambient temperature, moisture, and C:N.

A combined decrease in moisture and ambient temperature (Figure 3.6) or in ambient temperature and C:N (Figure 3.7) resulted in increased Bacillus species concentration ($P < 0.05$). Bacillus species were affected more drastically in low moisture levels. At a moisture level of 27% (Figure 3.8), low ambient temperatures and high C:N result in extremely low Bacillus species concentration while low C:N and low or high ambient temperatures result in extremely high or moderate Bacillus species concentration, respectively ($P < 0.05$). When moisture was high at 70% (Figure 3.9), C:N had a lesser effect on Bacillus species concentration, reducing the concentration during high ambient temperatures and high C:N ($P < 0.05$).

At low moisture levels and high (greater than 9.29 m$^2$/cow) or low (less than 9.29 m$^2$/cow) space per cow, Bacillus species were reduced or increased, respectively ($P < 0.05$, Figure 3.10). Alternatively, at high (greater than 60%) moisture levels, Bacillus species concentration increased with increasing space per cow ($P < 0.05$, Figure 3.11). Space per cow’s interaction with ambient temperature had a different trend. At low a space per cow, decreasing ambient temperature increased Bacillus species concentration ($P < 0.05$, Figure 3.12). However, at a high space per cow, increasing ambient temperature resulted in a slight increase in Bacillus species concentration. This trend continued when observing the interaction between moisture, space per cow, and ambient temperature on Bacillus species concentration. In low moisture conditions (Figure 3.13), high space per cow and low ambient temperatures resulted in decreased Bacillus species concentration while low space per cow and low ambient temperatures resulted in
increased Bacillus species concentration \( (P < 0.05) \). Conversely, in high moisture conditions (Figure 3.14), increasing space per cow and increasing ambient temperature or reducing space per cow and decreasing ambient temperature resulted in a gradual decrease in Bacillus concentration \( (P < 0.05) \)

Bacillus bacteria are rod shaped, gram-positive, spore-forming bacteria, which may be aerobic or anaerobic (Parrott-Sheffer and Rogers, 2012). Bacillus bacteria are rarely the cause of mastitis (Brown and Scherer, 1957, Howell, 1972, Jones and Turnbull, 1981); however, Bacillus spores can survive pasteurization, reducing milk shelf life (Griffiths, 1992, Jones and Turnbull, 1981). Bacillus species survive at a wide temperature range with maximum growth temperatures ranging from 31 to 76 °C. Optimal growth temperature is typically 6 °C below the maximum growth temperature. This characteristic makes Bacillus a difficult pathogen to destroy. Bacillus plays an active role in composting (Beffa et al., 1996), increasing the likelihood of the teats contacting the bacteria. However, not all Bacillus species are pathogenic (González, 1996) and many of the Bacillus bacteria are not a mastitis threat.

Bacillus species thrive in environments similar to composting bacteria, making Bacillus species reduction while maintaining active composting difficult. One management strategy is to provide more space per cow during winter weather to avoid excessive moisture addition to the CBP.

**Management**

Mastitis-causing bacteria thrive in similar conditions to that of composting bacteria and microbes making elimination of these bacteria difficult in an active composting environment. In commercial composting, material is sanitized because the
process is fully completed, killing bacteria in the different heating stages (Stentiford, 1996). However, in the CBP system, producers attempt to manage the CBP at a consistent stage to promote material degradation, making the system a “semi-composting” process. Additionally, bedding, manure, and urine are added to the CBP regularly, supplying carbon and nitrogen to mastitis-causing and composting bacteria alike.

Bacteria levels are not likely to be reduced by managing CBP moisture, temperature, C:N, and space per cow. Therefore, the producer’s aim should be to provide a dry lying surface to prevent dirty cows and increased SCC. This should be achieved by managing the composting process and through adequate bedding addition to reduce moisture on the surface layer. Increased moisture and nutrient availability in sawdust bedding increased bacterial concentrations (Fairchild et al., 1982, Zdanowicz et al., 2004). Further, a correlation existed between bedding bacterial counts and stall cleanliness in freestalls (Zdanowicz et al., 2004). However, contrary to previous belief, managing cows to remain standing after milking did not reduce the odds of intramammary infection (DeVries et al., 2010) making a dry lying surface even more crucial. In periods of inadequate composting activity and high CBP moisture, cow cleanliness should take precedence. Additional bedding should be added to reduce the risk of intramammary infection from increased exposure to pathogens (Neave et al., 1969) when housed on bedding with high bacteria concentrations (Hogan and Smith, 1997, Hogan et al., 1989, Zdanowicz et al., 2004).

The lying environment of cows housed on the CBP contained high bacteria levels compared to fresh bedding (Fairchild et al., 1982, Hogan and Smith, 1997) or pasture (S.
uberis, Lopez-Benavides et al., 2007). Therefore, attention must be paid to other management areas where preventative measures can be taken, such as during the dry period, at calving, and with replacement heifers. Additionally, meticulous parlor procedures (USDA/APHIS, 2003) are necessary to prevent contagious pathogen spread during milking.

CONCLUSIONS

Mastitis-causing bacteria thrive in the CBP environment, which meets the moisture and nutrient demands of the bacteria. Managing the CBP system for moisture, temperature, C:N, and space per cow may help to reduce some bacterial species concentrations, but the bacterial load in the bedding will likely remain high. Producers should manage the CBP for moisture to maintain a dry resting surface for cows to help prevent increased SCC and intramammary infections. The CBP provides a comfortable environment for cows but must be carefully managed to ensure udder health is not compromised.

ACKNOWLEDGEMENTS

We would like to thank the participating producers for their cooperation in this study. We extend our gratitude to the University of Kentucky County Extension Agents and Kentucky Dairy Development Council consultants who assisted with the project. Additionally, we would like to thank University of Kentucky Regulatory Services for their financial and laboratory assistance throughout the study.
Table 3.1. Pearson correlations between bacterial species and management or compost parameters considered to affect bacterial counts within the compost bedded pack barn.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coliform species</th>
<th><em>Escherichia coli</em></th>
<th>Staphylococcus species</th>
<th>Streptococcus species</th>
<th>Bacillus species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space per cow[^2^], m[^2^]/cow</td>
<td>-0.08</td>
<td>-0.03</td>
<td>0.05</td>
<td>-0.38[^*^]</td>
<td>0.07</td>
</tr>
<tr>
<td>Composite temperature[^3^], ºC</td>
<td>0.42[^*^]</td>
<td>0.54[^*^]</td>
<td>0.27</td>
<td>-0.01</td>
<td>0.00</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>-0.34[^*^]</td>
<td>-0.45[^*^]</td>
<td>-0.44[^*^]</td>
<td>0.03</td>
<td>-0.07</td>
</tr>
<tr>
<td>C:N[^4^]</td>
<td>0.01</td>
<td>-0.17</td>
<td>-0.52[^*^]</td>
<td>-0.03</td>
<td>-0.29</td>
</tr>
<tr>
<td>Ambient temperature, ºC</td>
<td>0.29</td>
<td>0.46[^*^]</td>
<td>0.53[^*^]</td>
<td>0.08</td>
<td>0.08</td>
</tr>
<tr>
<td>Tilling frequency, times/d</td>
<td>0.03</td>
<td>-0.05</td>
<td>-0.28</td>
<td>-0.18</td>
<td>-0.30</td>
</tr>
<tr>
<td>Tilling depth, cm</td>
<td>0.19</td>
<td>0.17</td>
<td>0.06</td>
<td>0.03</td>
<td>0.09</td>
</tr>
<tr>
<td>Amount of bedding added[^5^], m[^3^]/d</td>
<td>0.13</td>
<td>-0.05</td>
<td>-0.15</td>
<td>-0.29</td>
<td>0.05</td>
</tr>
<tr>
<td>Percent of d spent on pasture</td>
<td>0.10</td>
<td>0.07</td>
<td>0.15</td>
<td>-0.06</td>
<td>0.13</td>
</tr>
</tbody>
</table>

[^*^]P < 0.05
Table 3.1. cont.

1 All bacterial species tested using log transformation

2 Total compost bedded pack area divided by total number of lactating cows housed on pack

3 Mean of surface and 10.2 cm depth temperature

4 Carbon to nitrogen ratio

5 Amount of bedding (m³) added during addition of new bedding divided by d between new bedding additions
Table 3.2. Descriptive statistics for bacterial species sampled on 47 compost bedded pack barns in Kentucky.

<table>
<thead>
<tr>
<th>Bacteria Species</th>
<th>Mean (cfu/g)</th>
<th>SD (cfu/g)</th>
<th>Min (cfu/g)</th>
<th>Max (cfu/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coliform species</td>
<td>2,625,851</td>
<td>4,713,160</td>
<td>65,000</td>
<td>24,750,000</td>
</tr>
<tr>
<td><em>Escherichia coli</em></td>
<td>1,468,830</td>
<td>2,840,168</td>
<td>30,000</td>
<td>17,300,000</td>
</tr>
<tr>
<td>Streptococcal species</td>
<td>29,022,850</td>
<td>60,827,099</td>
<td>236,250</td>
<td>359,500,000</td>
</tr>
<tr>
<td>Staphylococcal species</td>
<td>73,643,617</td>
<td>135,251,081</td>
<td>1,000,000</td>
<td>900,000,000</td>
</tr>
<tr>
<td>Bacillus species</td>
<td>35,571,840</td>
<td>37,914,344</td>
<td>721,500.00</td>
<td>181,000,000</td>
</tr>
</tbody>
</table>
Table 3.3. Test of significance of explanatory variables for mean Coliform species concentration general linear model for 42 compost bedded pack barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator DF</th>
<th>Denominator DF</th>
<th>Type 3 SS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F Value</td>
<td>P Value</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature, ºC</td>
<td>0.01</td>
<td>0.92</td>
<td></td>
</tr>
<tr>
<td>Moisture, %</td>
<td>1.93</td>
<td>0.17</td>
<td></td>
</tr>
<tr>
<td>Space per cow¹, m²/cow</td>
<td>0.26</td>
<td>0.61</td>
<td></td>
</tr>
<tr>
<td>C:N²</td>
<td>3.35</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Composite temperature³, ºC</td>
<td>2.81</td>
<td>0.10</td>
<td></td>
</tr>
</tbody>
</table>

*R² = 0.273

¹Total compost bedded pack area divided by number of cows housed on pack

²Carbon to Nitrogen ratio

³Mean of surface and 10.2 cm depth pack temperatures
Table 3.4. Estimated coefficients for model of Coliform species concentration.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>13.7087</td>
<td>1.97</td>
<td>6.97</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature, °C</td>
<td>0.0034</td>
<td>0.03</td>
<td>0.10</td>
<td>0.92</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>-0.0337</td>
<td>0.02</td>
<td>-1.39</td>
<td>0.17</td>
</tr>
<tr>
<td>Space per cow(^1), m(^2)/cow</td>
<td>-0.0427</td>
<td>0.08</td>
<td>-0.51</td>
<td>0.61</td>
</tr>
<tr>
<td>C:N(^2)</td>
<td>0.0575</td>
<td>0.03</td>
<td>1.83</td>
<td>0.08</td>
</tr>
<tr>
<td>Composite temperature(^3), °C</td>
<td>0.0373</td>
<td>0.02</td>
<td>1.68</td>
<td>0.10</td>
</tr>
</tbody>
</table>

\(^1\)Total compost bedded pack area divided by number of cows housed on pack

\(^2\)Carbon to Nitrogen ratio

\(^3\)Mean of surface and 10.2 cm depth pack temperatures
Table 3.5. Test of significance of explanatory variables for mean *Escherichia coli* concentration general linear model for 42 compost bedded pack barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator</th>
<th>Denominator</th>
<th>Type 3 SS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DF</td>
<td>DF</td>
<td>F Value</td>
</tr>
<tr>
<td>Ambient temperature, ° C</td>
<td>1</td>
<td>35</td>
<td>0.88</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>1</td>
<td>35</td>
<td>1.97</td>
</tr>
<tr>
<td>Space per cow&lt;sup&gt;1&lt;/sup&gt;, m&lt;sup&gt;2&lt;/sup&gt;/cow</td>
<td>1</td>
<td>35</td>
<td>0.00</td>
</tr>
<tr>
<td>C:N&lt;sup&gt;2&lt;/sup&gt;</td>
<td>1</td>
<td>35</td>
<td>4.92</td>
</tr>
<tr>
<td>Composite temperature&lt;sup&gt;3&lt;/sup&gt;, ° C</td>
<td>1</td>
<td>35</td>
<td>2.32</td>
</tr>
<tr>
<td>C:N C:N</td>
<td>1</td>
<td>35</td>
<td>4.14</td>
</tr>
</tbody>
</table>

*R<sup>2</sup> = 0.413

<sup>1</sup>Total compost bedded pack area divided by number of cows housed on pack

<sup>2</sup>Carbon to Nitrogen ratio

<sup>3</sup>Mean of surface and 10.2 cm depth pack temperatures
Table 3.6. Estimated coefficients for model of *Escherichia coli* species concentration.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>9.0288</td>
<td>2.65</td>
<td>3.41</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature, ° C</td>
<td>0.0315</td>
<td>0.03</td>
<td>0.94</td>
<td>0.35</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>-0.0354</td>
<td>0.03</td>
<td>-1.40</td>
<td>0.17</td>
</tr>
<tr>
<td>Space per cow¹, m²/cow</td>
<td>-0.0008</td>
<td>0.09</td>
<td>-0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>C:N²</td>
<td>-0.3351</td>
<td>0.15</td>
<td>2.22</td>
<td>0.03</td>
</tr>
<tr>
<td>Composite temperature³, ° C</td>
<td>0.0350</td>
<td>0.02</td>
<td>1.52</td>
<td>0.14</td>
</tr>
<tr>
<td>C:N C:N</td>
<td>-0.0052</td>
<td>0.00</td>
<td>-2.03</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

¹Total compost bedded pack area divided by number of cows housed on pack

²Carbon to Nitrogen ratio

³Mean of surface and 10.2 cm depth pack temperatures
Table 3.7. Test of significance of explanatory variables for mean Staphylococcal species concentration general linear model for 42 compost bedded pack barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator</th>
<th>Denominator</th>
<th>Type 3 SS</th>
<th>F Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DF</td>
<td>DF</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient temperature, °C</td>
<td>1</td>
<td>36</td>
<td>4.20</td>
<td>&lt; 0.05</td>
<td></td>
</tr>
<tr>
<td>Moisture, %</td>
<td>1</td>
<td>36</td>
<td>0.00</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>Space per cow¹, m²/cow</td>
<td>1</td>
<td>36</td>
<td>0.76</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td>C:N²</td>
<td>1</td>
<td>36</td>
<td>3.78</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Composite temperature³, °C</td>
<td>1</td>
<td>36</td>
<td>0.93</td>
<td>0.34</td>
<td></td>
</tr>
</tbody>
</table>

*R² = 0.372

¹Total compost bedded pack area divided by number of cows housed on pack

²Carbon to Nitrogen ratio

³Mean of surface and 10.2 cm depth pack temperatures
Table 3.8. Estimated coefficients for model of Staphylococcal species concentration.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>19.2573</td>
<td>1.55</td>
<td>12.45</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature, ° C</td>
<td>0.0534</td>
<td>0.03</td>
<td>2.05</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>-0.0001</td>
<td>0.02</td>
<td>-0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Space per cow(^1), m(^2)/cow</td>
<td>-0.0572</td>
<td>0.07</td>
<td>-0.87</td>
<td>0.39</td>
</tr>
<tr>
<td>C:N(^2)</td>
<td>-0.0480</td>
<td>0.02</td>
<td>-1.94</td>
<td>0.06</td>
</tr>
<tr>
<td>Composite temperature(^3), ° C</td>
<td>-0.0169</td>
<td>0.02</td>
<td>-0.96</td>
<td>0.34</td>
</tr>
</tbody>
</table>

\(^1\)Total compost bedded pack area divided by number of cows housed on pack

\(^2\)Carbon to Nitrogen ratio

\(^3\)Mean of surface and 10.2 cm depth pack temperatures
Table 3.9. Test of significance of explanatory variables for mean Streptococcal species concentration general linear model for 42 compost bedded pack barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator</th>
<th>Denominator</th>
<th>Type 3 SS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DF</td>
<td>DF</td>
<td>F Value</td>
</tr>
<tr>
<td>Ambient temperature, °C</td>
<td>1</td>
<td>28</td>
<td>12.54</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>1</td>
<td>28</td>
<td>0.02</td>
</tr>
<tr>
<td>Space per cow¹, m²/cow</td>
<td>1</td>
<td>28</td>
<td>14.65</td>
</tr>
<tr>
<td>C:N²</td>
<td>1</td>
<td>28</td>
<td>23.85</td>
</tr>
<tr>
<td>Composite temperature³, °C</td>
<td>1</td>
<td>28</td>
<td>8.29</td>
</tr>
<tr>
<td>C:N C:N</td>
<td>1</td>
<td>28</td>
<td>23.28</td>
</tr>
<tr>
<td>Moisture C :N</td>
<td>1</td>
<td>28</td>
<td>19.02</td>
</tr>
<tr>
<td>Moisture s pace per cow</td>
<td>1</td>
<td>28</td>
<td>13.53</td>
</tr>
<tr>
<td>Space per cow a mbient temperature</td>
<td>1</td>
<td>28</td>
<td>13.42</td>
</tr>
<tr>
<td>Moisture ambient temperature</td>
<td>1</td>
<td>28</td>
<td>11.85</td>
</tr>
<tr>
<td>Composite temperature C :N</td>
<td>1</td>
<td>28</td>
<td>7.90</td>
</tr>
<tr>
<td>Moisture C:N C :N</td>
<td>1</td>
<td>28</td>
<td>20.64</td>
</tr>
<tr>
<td>Moisture s pace per cow a mbient</td>
<td>1</td>
<td>28</td>
<td>11.33</td>
</tr>
</tbody>
</table>

*R² = 0.684

¹Total compost bedded pack area divided by number of cows housed on pack

²Carbon to Nitrogen ratio

³Mean of surface and 10.2 cm depth pack temperatures
Table 3.10. Estimated coefficients for model of Streptococcal species concentration.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>22.5329</td>
<td>13.26</td>
<td>1.70</td>
<td>0.10</td>
</tr>
<tr>
<td>Ambient temperature, °C</td>
<td>-2.4117</td>
<td>0.68</td>
<td>-3.54</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>-0.0363</td>
<td>0.23</td>
<td>-0.16</td>
<td>0.88</td>
</tr>
<tr>
<td>Space per cow(^1), m(^2)/cow</td>
<td>-4.5592</td>
<td>1.19</td>
<td>-3.83</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>C:N(^2)</td>
<td>4.8338</td>
<td>0.99</td>
<td>4.88</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Composite temperature(^3), °C</td>
<td>-0.2742</td>
<td>0.10</td>
<td>-2.88</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture : C:N</td>
<td>-1.227</td>
<td>0.03</td>
<td>-4.82</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture : space per cow</td>
<td>-0.0737</td>
<td>0.02</td>
<td>-4.36</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Space per cow : ambient temperature</td>
<td>0.0688</td>
<td>0.02</td>
<td>3.68</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture : ambient temperature</td>
<td>0.2370</td>
<td>0.06</td>
<td>3.66</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Composite temperature : C:N</td>
<td>0.0089</td>
<td>0.00</td>
<td>2.81</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture : C:N : C:N</td>
<td>0.0018</td>
<td>0.00</td>
<td>4.54</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture : space per cow : ambient temperature</td>
<td>-0.0034</td>
<td>0.00</td>
<td>-3.37</td>
<td>&lt; 0.01</td>
</tr>
</tbody>
</table>

\(^1\)Total compost bedded pack area divided by number of cows housed on pack

\(^2\)Carbon to Nitrogen ratio

\(^3\)Mean of surface and 10.2 cm depth pack temperatures
Table 3.11. Test of significance of explanatory variables for Bacillus species concentration general linear model for 42 compost bedded pack barns in Kentucky.*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Numerator DF</th>
<th>Denominator DF</th>
<th>Type 3 SS F Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature, ° C</td>
<td>1</td>
<td>29</td>
<td>9.93</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>1</td>
<td>29</td>
<td>7.93</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Space per cow(^1), m(^2)/cow</td>
<td>1</td>
<td>29</td>
<td>10.33</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>C:N(^2)</td>
<td>1</td>
<td>29</td>
<td>3.81</td>
<td>0.06</td>
</tr>
<tr>
<td>Composite temperature(^3), ° C</td>
<td>1</td>
<td>29</td>
<td>0.02</td>
<td>0.88</td>
</tr>
<tr>
<td>Ambient temperature space per cow</td>
<td>1</td>
<td>29</td>
<td>11.57</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature moisture</td>
<td>1</td>
<td>29</td>
<td>10.24</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature C:N</td>
<td>1</td>
<td>29</td>
<td>4.75</td>
<td>0.04</td>
</tr>
<tr>
<td>Moisture space per cow</td>
<td>1</td>
<td>29</td>
<td>10.06</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture C:N</td>
<td>1</td>
<td>29</td>
<td>3.51</td>
<td>0.07</td>
</tr>
<tr>
<td>Ambient temperature moisture space per cow</td>
<td>1</td>
<td>29</td>
<td>10.63</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature moisture C:N</td>
<td>1</td>
<td>29</td>
<td>5.38</td>
<td>0.03</td>
</tr>
</tbody>
</table>

\(*R^2 = 0.395\)

\(^1\)Total compost bedded pack area divided by number of cows housed on pack

\(^2\)Carbon to Nitrogen ratio

\(^3\)Mean of surface and 10.2 cm depth pack temperatures
Table 3.12. Estimated coefficients for model of Bacillus species concentration.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Standard Error</th>
<th>T Value</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>94.2765</td>
<td>26.66</td>
<td>3.54</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature, ° C</td>
<td>-4.1375</td>
<td>1.31</td>
<td>-3.15</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>-1.1620</td>
<td>0.41</td>
<td>-2.82</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Space per cow¹, m²/cow</td>
<td>-4.3041</td>
<td>1.34</td>
<td>-3.21</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>C:N²</td>
<td>-1.37</td>
<td>0.70</td>
<td>-1.95</td>
<td>0.06</td>
</tr>
<tr>
<td>Composite temperature³, ° C</td>
<td>-0.0045</td>
<td>0.03</td>
<td>-0.15</td>
<td>0.88</td>
</tr>
<tr>
<td>Ambient temperature space per cow</td>
<td>0.2314</td>
<td>0.07</td>
<td>3.40</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature moisture</td>
<td>0.0649</td>
<td>0.02</td>
<td>3.20</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature C:N</td>
<td>0.0728</td>
<td>0.03</td>
<td>2.18</td>
<td>0.04</td>
</tr>
<tr>
<td>Moisture space per cow</td>
<td>0.0671</td>
<td>0.02</td>
<td>3.17</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Moisture C :N</td>
<td>0.0199</td>
<td>0.01</td>
<td>1.87</td>
<td>0.07</td>
</tr>
<tr>
<td>Ambient temperature moisture space per cow</td>
<td>-0.0036</td>
<td>0.00</td>
<td>-3.26</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Ambient temperature moisture C:N</td>
<td>-0.0012</td>
<td>0.00</td>
<td>-2.32</td>
<td>0.03</td>
</tr>
</tbody>
</table>

¹Total compost bedded pack area divided by number of cows housed on pack

²Carbon to Nitrogen ratio

³Mean of surface and 10.2 cm depth pack temperatures
Figure 3.1. Sampling locations used to collect bedding material for bacterial and nutrient analyses. Points A1 through A9 indicated estimated distribution of sampling locations in each compost bedded pack barn visited.
Figure 3.2. Predicted regression of Streptococcal species concentration when moisture and C:N$^1$ vary on 42 compost bedded pack barns in Kentucky.

*C* $P < 0.05$

$^1$C:N = Carbon ÷ Nitrogen
Figure 3.3. Predicted regression of Streptococcal species concentration when C:N$^1$ and composite temperature$^2$ vary on 42 compost bedded pack barns in Kentucky.

* $P < 0.05$

$^1$C:N = Carbon ÷ Nitrogen

$^2$Mean of surface and 10.2 cm depth pack temperatures
Figure 3.4. Predicted regression of Streptococcal species concentration when ambient temperature and space per cow\(^1\) vary and moisture is maintained at 27% on 42 compost bedded pack barns in Kentucky.

\[ \text{Moisture} = 27\% \]

*\(P < 0.05\)

\(^1\)Total compost bedded pack area divided by number of cows housed on pack
Figure 3.5. Predicted regression of Streptococcal species concentration when ambient temperature and space per cow\(^1\) vary and moisture is maintained at 70\% on 42 compost bedded pack barns in Kentucky.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3.5.png}
\caption{Predicted Streptococcal Species Count (log\(_{10}\) cfu/g) vs. Space per Cow\(^1\) (m\(^2\)/cow) and Ambient Temperature (°C) at Moisture = 70\%.}
\end{figure}

\*\( P < 0.05 \)

\(^1\)Total compost bedded pack area divided by number of cows housed on pack
Figure 3.6. Predicted regression of Bacillus species concentration when moisture and ambient temperature vary on 42 compost bedded pack barns in Kentucky. 

*P < 0.05
Figure 3.7. Predicted regression of Bacillus species concentration when ambient temperature and C:N$^1$ vary on 42 compost bedded pack barns in Kentucky.

*P* < 0.05

$^1$C:N = Carbon ÷ Nitrogen
Figure 3.8. Predicted regression of Bacillus species concentration when ambient temperature and C:N\(^1\) vary and moisture is maintained at 27% on 42 compost bedded pack barns in Kentucky.

\[ P < 0.05 \]

\(^1\)C:N = Carbon ÷ Nitrogen
Figure 3.9. Predicted regression of Bacillus species concentration when ambient temperature and C:N\(^1\) vary and moisture is maintained at 70% on 42 compost bedded pack barns in Kentucky.

\* P < 0.05

\(^1\)C:N = Carbon ÷ Nitrogen
Figure 3.10. Predicted regression of Bacillus species concentration when moisture and C:N\(^1\) vary on 42 compost bedded pack barns in Kentucky.

\[ P < 0.05 \]

\(^1\)C:N = Carbon ÷ Nitrogen
Figure 3.11. Predicted regression of Bacillus species concentration when moisture and space per cow\(^1\) vary on 42 compost bedded pack barns in Kentucky.

\[
\text{Predicted Bacillus Species Count (log}_{10}\text{ cfu/g)}
\]

---

*\(P < 0.05\)

\(^1\)Total compost bedded pack area divided by number of cows housed on pack.
Figure 3.12. Predicted regression of Bacillus species concentration when ambient temperature and space per cow\(^1\) vary on 42 compost bedded pack barns in Kentucky.

\[ P < 0.05 \]

\(^1\)Total compost bedded pack area divided by number of cows housed on pack
Figure 3.13. Predicted regression of Bacillus species concentration when ambient temperature and space per cow\(^1\) vary and moisture is maintained at 27% on 42 compost bedded pack barns in Kentucky.

\[\begin{array}{|c|c|c|}
\hline
\text{Moisture = 27\%} & \text{Predicted Bacillus Species Count (log}_{10}\text{ cfu/g)} \\
\hline
\text{0-5} & \text{5-10} & \text{10-15} & \text{15-20} & \text{20-25} & \text{25-30} & \text{30-35} \\
\hline
\end{array}\]

*\(p < 0.05\)

\(^1\)Total compost bedded pack area divided by number of cows housed on pack
Figure 3.14. Predicted regression of Bacillus species concentration when ambient temperature and space per cow\(^1\) vary and moisture is maintained at 70% on 42 compost bedded pack barns in Kentucky.

\[
P < 0.05
\]

\(^1\)Total compost bedded pack area divided by number of cows housed on pack
CHAPTER FOUR

A decision support tool for investment analysis of new dairy housing facility construction

R.A. Black and J.M. Bewley

Department of Animal and Food Sciences, University of Kentucky, Lexington, KY 40546
INTRODUCTION

Investment decisions affect farm success by influencing farm profitability. Whether a farm is updating a barn, expanding, or starting a new dairy enterprise, choosing the most economically appropriate facility can dramatically influence profitability by improving or hindering milk production, cow comfort and health, or variable costs. Consultant advice, literature recommendations, and word of mouth typically dictate housing decisions, but each financial and management situation can dramatically affect the decision profitability. Not all producers’ management preferences, geography, or available resources are suited for every housing management system. Producer preference, financial status, and environmental considerations influence housing choice.

Economic models exist for different dairy decisions including reproduction (Demeter et al., 2011, Giordano et al., 2011, Giordano et al., 2012, Lassen et al., 2007, Plaizier et al., 1997), culling (Cabrera, 2010, 2012, Groenendaal et al., 2004, Marsh et al., 1987), nutrient management (Cabrera, 2010, Schils et al., 2007), farm machinery costs (Lazarus, 2009), anaerobic digesters (Lazarus et al., 2011), environmental emissions (Rotz et al., 2010), and mastitis (Charlier et al., 2012, Østergaard et al., 2005, Swinkels et al., 2005). Many of these decisions are made on a daily basis while others are made more infrequently. The useful life of dairy housing is typically 15 to 20 y (Thomas et al., 1994), making housing investment decisions infrequent. However, Wisconsin dairy farmers are expected to spend nearly 50% of total expected investment dollars on new dairy facilities or improvements from 2011 to 2015 ($535,440 of $1,180,080 expected dairy facility investment, NASS, 2010). Horner et al. (2007) produced models depicting
29 different management situations. Each model varied by cow number (200, 700, or 3,000 cows), ventilation system (natural or mechanical), bedding type (compost bedded pack (CBP) barn, mattress base freestall (MF) barn, sand base freestall (SF) barn, or grazing), and manure handling system (manure pit, slurry scrape, or flush system).

Knoblauch and Galton (1997) investigated the investment costs related to three different freestall housing systems and differing roof insulation levels. Lazarus et al. (2003) investigated the investment profitability of farmer’s continuing to milk in an existing tie-stall barn, expanding the existing tie-stall barn by 50%, or converting the existing tie-stall barn to a milking parlor and constructing a new freestall barn, or constructing all new milking a housing facilities. Continuing to milk in existing facilities projected a yearly income of $53,907. However, expanding that facility by 50% would not likely increase income enough because additional labor would be required. Converting the existing tie-stall barn to a milking parlor and building a new freestall barn would likely increase net farm income to $70,954 because of improved labor efficiency. Constructing all new facilities would improve labor efficiency and generate more income or $156,714; however, capital requirements would also increase substantially. The authors concluded that risk preference and credit worthiness influenced equity required to make a major farm investment. Producers using the models must choose a scenario best matching their farm situation instead of using an interactive model, which allows flexibility in the values used to calculate investment profitability.

Common indoor dairy housing facilities include MF, SF, and CBP barns. Mattress base freestall barns allow each cow an individual stall to lie in. Each stall contains a mattress or waterbed, typically a heavyweight polyurethane cover filled with
shredded recycled rubber or water, respectively, bedded with absorbent material 5.1 to 10.2 cm high, commonly sawdust or straw. Some farms use rubber mats, or other compressed material, as a mattress base, but these materials but these materials do not supply appropriate cushion when cows rise or lay down, possibly leading to increased hock lesions (Weary and Taszkun, 2000). Cows may move about the enclosed area, able to navigate freely to the feedbunk or waterer (MWPS, 2000). The SF barn is similar in nature to the MF barn; however, instead of mattresses as a freestall base, stalls are hollow allowing for deep bedding of sand with a 15.2 cm minimum depth (MWPS, 2000). The inorganic nature of sand reduces pathogen growth potentially infecting the udder (Hogan et al., 1989, Kristula et al., 2005, Zdanowicz et al., 2004). Other materials commonly used for a deep-bedded stall include ground limestone, sawdust, straw, and recycled manure solids (MWPS, 2000). A CBP barn involves similar barn structural design, but the infrastructure is different. Instead of individual stalls, the pen area is an open area bedded with sawdust mixed with manure and urine. The bedded area provides a soft resting and standing area, potentially reducing lameness within the herd (Phillips and Schofield, 1994). The feed alley and milking facilities are typically the same as those observed in freestall barns (Janni et al., 2007).

A partial budget analysis assumes increases and reductions in income, and increases and reductions in costs due to a change on the farm (Tigner, 2006). New dairy housing will may increase bedding, feed, and lameness costs, but reduce labor and mastitis costs. Producers hope to offset cost by increased milk production and milk quality income. Parameters used to assess the economic viability of a housing option using a partial budget analysis include NPV and IRR. Net present value is the difference
between added returns and costs incorporating the time value of money. The discount rate (DR), or the acceptable rate of return on an investment set by the producer, influences the NPV. When the NPV is greater than or equal to zero, the investment decisions is considered economically viable, with the IRR having equaled or exceeded the DR. However, a NPV less than zero indicated a non-economically viable investment decision, where the IRR did not meet the DR and benefits of the decision did not outweigh costs (Butler, 1996).

The intention of this research was to provide an assessment of the economic viability of new dairy housing facilities using a partial budget analysis to illustrate potential costs and benefits of each system given a set of default values. Variable costs were determined which resulted in a NPV greater than or equal to zero through sensitivity analyses. Sensitivity analyses also evaluated changes in the NPV when variable and fixed costs varied. A farm-specific, user-friendly dashboard was developed, which would allow farmers to use the information in the model and set cow performance and farm financial parameters to match those specific to their farm situation, resulting in a user-specific partial budget analysis for the different systems.

**MATERIALS AND METHODS**

A model was developed to evaluate the economic implications of investment in a new dairy facility. The analysis included capital costs related to building construction and changes in bedding use, labor, and feed. The analysis also incorporated increased profits related to increased milk production and reduced lameness prevalence and SCC.
Model Structure.

The model was developed by using existing literature to produce default management and construction value assumptions. Academic and industry experts were consulted for additional necessary information. Table 1 describes default values used and the source of information. The model includes values for an assumed current management system, which the producer is transitioning from, and a future dairy housing facility. Facilities included a MF, a SF, and a CBP barn.

Current Housing. Producers move into new housing for reasons including herd expansion, new management direction, and entry into the dairy industry. Default values assumed producers were transitioning from a grazing dairy system to an indoor housing system. Kentucky dairy producers still widely use pasture-grazing systems (Russell and Bewley, 2011). Indoor housing is an option to alleviate some consequences associated with pastured herds, such as suppressed milk production and composition and elevated SCC caused by heat stress and harsh conditions in the pasture environment (Fike et al., 2002, Smith and Ely, 1997). Additionally, the modeled conditions assume no expansion of the herd upon moving into the new housing facility. Input values could be changed within the dashboard for other scenarios. Current lactating herd size was determined using Equation 4.1:

\[
COWS_L = COWS_A \cdot PH_L
\]  

(Eq. 4.1)

Where COWS\(_L\) is the lactating herd size, COWS\(_A\) is the herd size including both lactating and dry cows, and PH\(_L\) is the percent of the herd that is lactating. Estimated 10-y milk price represents a less variable price than current milk price, which displays volatility depending on commodity pricing and governmental regulation. A projected 10-
y mean was calculated from future estimated milk prices (Westhoff et al., 2012) and used for further calculations. Lactating cow feed costs were calculated using 10-y mean projected feed costs (FAPRI, 2012) and Equation 4.2 (Bailey and Ishler, 2007):

\[
FC = \left( \frac{51}{56} \right) CP + \left( \frac{8}{60} \right) SP + \left( \frac{41}{2000} \right) AP \times 2.2
\]

(Eq. 4.2)

Where FC is the cost ($) per kg DM, CP is the cost ($) per hundredweight (cwt) of corn, SP is the cost ($) per cwt of soybean, AP is the cost ($) per cwt of alfalfa, 100 converts price from cwt to pounds (lb), and 2.2 converts price from $/lb DM to $/kg DM.

Each housing system offers different costs and benefits associated with investment and management costs, and animal health and performance. Producer personal preferences and management style vary and play a role in the level of achievement for benefits or degree of costs.

**Planned Housing: Construction and Management.** Building costs are the major source of investment cost when constructing new housing. Compost bedded pack barns have lower investment costs compared to freestall barns (CBP: $1,051 per cow, Black et al., 2012; SF: $1,800 per stall, Horner et al., 2007; MF: $1,950 per stall, Horner et al., 2007) because of reduced concrete requirement and the lack of stall hardware, though some states do require a concrete base to reduce nutrient leakage (Barberg et al., 2007a, Janni et al., 2007). Prices vary depending on amount of work contracted, geography, concrete prices, material costs, and market variability. More space per cow is necessary requiring a larger structure with fewer animals to handle the moisture input into the CBP. A 100% stocking density was assumed for all housing facilities where 100% is one stall
per cow in freestall housing and 9.8m² per cow in CBP (Wagner, 2002). Building cost was calculated using Equation 4.3:

\[
\text{COST}_B = \text{COST}_S \times \text{STALL} \quad \text{(Eq. 4.3)}
\]

Where \(\text{COST}_B\) is the total cost ($) of the barn, \(\text{COST}_S\) is the cost ($) per stall or cost ($) per cow space, including concrete, stall hardware, and mechanical ventilation (if used), and \(\text{STALL}\) is the number of stalls within the barn. Management costs increase in a housing facility compared to grazing because of additional labor needs required to rake stalls and scrape alleyways clean of manure and stir the CBP to promote composting. However, some labor costs are reduced because cows are closer to the milking parlor and require less time to move to the holding pen. Time required to rake stalls was calculated using Equation 4.4:

\[
\text{RAKE} = \frac{\text{TIME}_S \times \text{STALL}}{60} \quad \text{(Eq. 4.4)}
\]

Where \(\text{RAKE}\) is the time (m) to rake all stalls in the barn, \(\text{TIME}_S\) is the time (s) spent to rake each individual stall, \(\text{STALL}\) is the number of stalls within the barn, and 60 converts s to m. Equation 4.5 was used to calculate the annual change in labor cost for the CBP barn:

\[
\text{COST}_{CL} = \left(\frac{((\text{MOVE}_p + \text{STIR} + \text{SCRAPE}) - \text{MOVE}_c)}{60}\right) \times \text{COST}_L \quad \text{(Eq. 4.5)}
\]

Where \(\text{COST}_{CL}\) is the change in labor cost when moving to the new facility, \(\text{MOVE}_p\) is the predicted time (m) to move cows to the holding pen, \(\text{STIR}\) is the predicted time (m) to stir the pack, \(\text{SCRAPE}\) is the predicted time (m) to scrape the alleyways, \(\text{MOVE}_c\) is the current time (m) to move cows to the holding pen, 60 converts m to h, and
COST_{L} is the cost of labor ($/h). Equation 4.6 was used to calculate the annual change in labor cost for a freestall barn:

\[
\text{COST}_{CL} = \frac{\left( \text{MOVE}_{P} + \text{RAKE} + \text{SCRAPE} \right) - \text{MOVE}_{C}}{60} \times \text{COST}_{L} \quad \text{(Eq. 4.6)}
\]

Where COST_{CL} is the change in labor cost when moving to the new facility, MOVE_{P} is the predicted time (m) to move cows to the holding pen, RAKE is the predicted time (m) to rake all the stalls in the barn, SCRAPE is the predicted time (m) to scrape the alley ways, MOVE_{C} is the current time (m) to move cows to the holding pen, COST_{L} is the cost of labor ($/h), and 60 converts m to h. Bedding costs increase when moving from pasture to housing and increase more for the SF and CBP barns compared to MF barn. Bedding acts as the primary lying surface in the CBP and SF barns and as a means to reduce abrasive forces when a cow rises or lies down in the MF barn. Sand freestalls are deep bedded stalls which require a minimum bedding depth of 15.2 cm (MWPS, 2000) to provide a comfortable lying surface. The entire floor of the CBP must be covered with a minimum of 50 cm of bedding to maintain an active composting environment (Galama et al., 2011) while bedding is only necessary in the stall area in MF and SF barns. Additionally, more bedding is necessary to absorb the moisture because the CBP retains most moisture excreted by cows except that excreted in the feed alley. Conversely, MF and SF barns allow excrement to reside in the underground pit or concrete alleyways, which are scraped into a manure slurry lagoon for storage. Equation 4.7 was used to calculate the annual cost of sawdust bedding for CBP:

\[
\text{COST}_{BD} = \frac{\text{AMOUNT}_{D}}{\text{DAYS}} \times \text{COST}_{SW} \times 365.25 \quad \text{(Eq. 4.7)}
\]
Where \( \text{COST}_{\text{BD}} \) is the cost ($) of sawdust bedding per y, \( \text{AMOUNTD} \) is the average amount (\( \text{m}^3 \)) of sawdust bedding per bedding addition, \( \text{DAYS} \) is the number of d between bedding additions, \( \text{COST}_{\text{SW}} \) is the cost ($) per \( \text{m}^3 \) of sawdust bedding, and 365.25 accounts for annual bedding use. Equation 4.8 was used to calculate the annual cost of sawdust bedding for MF:

\[
\text{COST}_{\text{BD}} = \frac{\text{AMOUNTD}}{\text{DAYS}} \times \text{COST}_{\text{SW}} \times \text{COWSL} \times 365.25 \quad \text{(Eq. 4.8)}
\]

Where \( \text{COST}_{\text{BD}} \) is the cost ($) of sawdust bedding per y, \( \text{AMOUNTD} \) is the average amount (\( \text{m}^3 \)) of sawdust bedding per bedding addition, \( \text{DAYS} \) is the number of d between bedding additions, \( \text{COST}_{\text{SW}} \) is the cost ($) per \( \text{m}^3 \) of sawdust bedding, \( \text{COWSL} \) is the lactating herd size, and 365.25 accounts for annual bedding use. Equation 4.9 was used to calculate the annual cost of sand bedding for SF:

\[
\text{COST}_{\text{BD}} = \text{COST}_{\text{SD}} \times \frac{\text{AMOUNTS}}{\text{STALL}} \times 365.25 \quad \text{(Eq. 4.9)}
\]

Where \( \text{COST}_{\text{BD}} \) is the cost ($) of sand bedding per d, \( \text{COST}_{\text{SD}} \) is the cost per kg of sand bedding, \( \text{AMOUNTS} \) is the amount (kg) of sand added per stall per d, \( \text{STALL} \) is the number of stalls in the barn, and 365.25 accounts for annual bedding use. Moving cows from an outdoor system to an indoor is expected to increase milk production and feed intake because of improved management and environmental control (Smith and Ely, 1997, White et al., 2002). Predicted daily milk production increase was converted to 4% fat-corrected milk (\( \text{FCM} \)) using Eq. 4.10 (NRC, 2001):

\[
\text{FCM} = (0.4 \times \text{MILK}) + (15 \times \text{MILK} \times \text{FAT}) \quad \text{(Eq. 4.10)}
\]

Where FCM is 4% fat corrected milk (kg), MILK is the predicted daily increase in milk production (kg), and FAT is the fat content of the milk (%). Feed intake was assumed to increase with increased milk production and calculated using a feed
efficiency ratio. However, the increase would not likely be an immediate change and occur over time once introduced to the new housing system. Performance and health changes experienced when transitioning to a new housing facility would likely occur gradually to allow animals to heal in cases of intramammary infection and lameness for the CBP (Barberg et al., 2007b), or worsen in cases of lameness in the MF and SF. Milk production is assumed to follow this gradual change to account for gradual increased DMI and reduced energy maintenance requirements from shorter walking distances (NRC, 2001). This model anticipates only 75% of a change in performance for the first y occupying a new facility, 85% during the second y, and 100% for all following y. Dry matter intake was calculated using Eq. 4.11:

\[
DMI = \frac{FCM}{FE} \text{ BENEFIT} \quad \text{(Eq. 4.11)}
\]

Where DMI is the dry matter intake (kg dry matter per cow) for the increased milk production per cow, FCM is the 4% fat corrected milk (kg), and FE is the feed efficiency ratio (kg DM per kg milk), and BENEFIT is the percent of change a performance or health parameter experiences from the new facility during that production y. Equation 4.12 was used to calculate annual increase in feed costs:

\[
COST_f = (FC \times DMI) \times \text{COWS}_L \times 365.25 \quad \text{(Eq. 4.12)}
\]

Where COST\(_f\) is the annual increase in feed cost ($) from the increase in milk production, FC is the feed cost ($/kg), DMI is the dry matter intake, COWS\(_L\) is the lactating herd size, and 365.25 accounts for the annual cost.

_Planmed Housing: Animal Health and Performance._ Benefits arise from the decision to house animals indoors because cows are within close proximity to daily farm management chores and can be monitored more closely. Milk production was modeled
to increase because cows were eating more of a formulated ration designed to increase milk production (MF: 2.5 kg per cow per d, Smith and Ely, 1997; SF: 2.5 kg per cow per d, Smith and Ely, 1997; CBP: 2.6 kg per cow per d, Barberg et al., 2007a). Therefore, the predicted daily increase in milk production after moving into a new housing facility was used to calculate Eq. 4.13.

\[ \text{MILK}_C = \text{MILK} \times \text{BENEFIT} \]  
(Eq. 4.13)

Where \( \text{MILK}_C \) is the daily increase in production (kg) per cow corrected for the benefit experienced, \( \text{MILK} \) is the predicted daily increase in milk production (kg) per cow, and \( \text{BENEFIT} \) is the percent of change a performance or health parameter experiences from the new facility during that production year. Equation 4.14 was used to calculate daily herd milk production increase:

\[ \text{MILK}_D = \text{MILK}_C \times \text{COWS}_L \]  
(Eq. 4.14)

Where \( \text{MILK}_D \) is the total daily increase in milk production (kg) for all lactating cows, \( \text{MILK}_C \) is the daily increase in production (kg) per cow, and \( \text{COWS}_L \) is the lactating herd size. Equation 4.15 was used to calculate annual herd milk yield increase:

\[ \text{MILK}_Y = \text{MILK}_D \times 365.25 \]  
(Eq. 4.15)

where \( \text{MILK}_Y \) is the total yearly increase in milk production (kg) for all lactating cows, \( \text{MILK}_D \) is the total daily increase in milk production (kg) for all lactating cows, and 365.25 accounts for annual production. Equation 4.16 was used to calculate the annual change in revenue from increased milk production:

\[ \text{MYR} = \text{MILK}_Y \times \text{MP} \]  
(Eq. 4.16)

Where \( \text{MYR} \) is the annual change in revenue ($) from milk yield, \( \text{MILK}_Y \) is the total yearly increase in milk production (kg) for all cows, and \( \text{MP} \) is the milk price ($/kg).
Along with production, udder health, as indicated by SCC, was assumed to improve when transitioning from a grazing system (357,000 cells/mL, USDA/NAHMS, 2012) to an indoor housing management system (MF: 357,000 cells/mL, USDA/NAHMS, 2012; SF: 272,000 cells/mL, USDA/NAHMS, 2012; CBP: 252,860 cells/mL, Black et al., 2012). Changes in milk production because of mastitis are not included in this model because the milk production increase would be overstated from the housing transition and improved udder health. As with milk production, udder health improvement does not occur instantaneously. Modeling this change as a percentage of improvement using the BENEFIT term more appropriately accounts for SCC gradual improvement. A change in SCC resulted in a reduction or increase in SCC bonus price depending on the SCC bonus structure (Table 2). Equation 4.17 was used to calculate previous annual bonus amount collected:

$$BONUS_{PT} = \left( BONUS \left( MY \right) \times COWS_{L} \right) \times 365.25$$  \hspace{1cm} \text{(Eq. 4.17)}$$

Where \(BONUS_{PT}\) is the total revenue ($) earned from the SCC bonus prior to the new facility, \(BONUS\) is the amount earned ($/kg) from the SCC bonus structure, \(MY\) is milk yield (kg) per cow per d, \(COWS_{L}\) is the lactating herd size, and 365.25 accounts for annual earnings. Equation 4.18 was used to calculate milk yield per cow:

$$MY = \frac{RHA}{P_{H_{L}}} \times 365.25$$  \hspace{1cm} \text{(Eq. 4.18)}$$

Where \(MY\) is milk yield (kg) per cow per d, \(RHA\) is the yearly rolling herd average milk production (kg), \(P_{H_{L}}\) is the percent of the herd that is lactating, and 365.25 accounts for the annual nature of the RHA. Equation 4.19 was used to calculate increased or decreased annual earnings from the SCC change due to the new facility:
\[ BONUS_{IT} = \left( MY + \left( MILK_c \times BENEFIT \right) \right) \times BONUS \times COWS_L \times 365.25 \quad (Eq. 4.19) \]

Where \( BONUS_{IT} \) is the total revenue ($) earned from the SCC bonus accounting for previous milk production and predicted increase in milk production experienced from the new facility, \( MY \) is milk yield (kg) per cow per d, \( MILK \) is the predicted daily increase in milk production from the new housing facility (kg) per cow, \( BENEFIT \) is the percent of change a production parameter experiences from the new facility during that production y, \( BONUS \) is the amount earned ($/kg) from the SCC bonus structure, \( COWS_L \) is the lactating herd size, and 365.25 accounts for an annual earning. Equation 4.20 was used to calculate the overall change in annual bonus earnings:

\[ BONUS_C = BONUS_{IT} - BONUS_{PT} \quad (Eq. 4.20) \]

Where \( BONUS_C \) is the annual change in revenue ($) earned from the SCC bonus, \( BONUS_{IT} \) is the total revenue ($) earned from the SCC bonus accounting for previous milk production and predicted increase in milk production experienced from the new facility, and \( BONUS_{PT} \) is the total revenue ($) currently earned from the SCC bonus prior to the new facility. Lameness incidence was greater in freestall facilities, particularly MF barns, compared to grazing systems and CBP barns (Grazing: 17.4%, Olmos, 2009; MF: 30.3%, Cook, 2003; SF: 19.8%, Cook, 2003; CBP: 12.0%, Black et al., 2012). Freestall housing requires concrete alleyways between stalls and in the feed alley while CBP only require concrete at the feed alley and grazing systems require little to no concrete depending on the milking system; therefore, cows housed in freestalls are exposed to more abrasive flooring, increasing the number of hoof disorders (Dewes, 1978, Galindo and Broom, 2000). The gradual change in lameness prevalence was accounted for by multiplying the expected change of lameness prevalence by the \( BENEFIT \) experienced.
Lameness cost included costs from reduced fertility and treatment and was averaged over three different lameness disorders, sole ulcer, digital dermatitis, and foot rot (Cha et al., 2010). Equation 4.21 was used to calculate the annual change in clinical lameness case cost:

\[
\text{COST}_{\text{CLT}} = \left( \left( \text{LAME}_p - \text{LAME}_c \right) \times \text{BENEFIT} \right) \times \text{COWS}_L \times \text{COST}_{\text{LT}} \quad \text{(Eq. 4.21)}
\]

Where \( \text{COST}_{\text{CLT}} \) is the change in lameness cost ($), \( \text{LAME}_p \) is the predicted lameness prevalence (%), \( \text{LAME}_c \) is the current lameness prevalence (%), \( \text{BENEFIT} \) is the percent of change a performance or health parameter experiences from the new facility during that production year, \( \text{COWS}_L \) is the lactating herd size, and \( \text{COST}_{\text{LT}} \) is the cost ($) of lameness treatment per cow.

**Net Present Value Calculation.** Profitability of a system is determined using the costs encountered through building a new housing system and the benefits experienced from improved management. Gross annual income change from moving into the new housing system is calculated using Equation 4.22:

\[
\text{INCOME}_G = \text{MY}_R + \text{BONUS}_C \quad \text{(Eq. 4.22)}
\]

Where \( \text{INCOME}_G \) is the gross annual increase in income, \( \text{MY}_R \) is the annual change in revenue ($) from milk yield, and \( \text{BONUS}_C \) is the annual change is revenue ($) earned from the SCC bonus. Equation 4.23 was used to calculate total annual increase in costs:

\[
\text{COST}_T = \text{COST}_{\text{BD}} + \text{COST}_F + \text{COST}_{\text{CL}} + \text{COST}_{\text{CLT}} \quad \text{(Eq. 4.23)}
\]

Where \( \text{COST}_T \) is the annual total increase in costs ($), \( \text{COST}_{\text{BD}} \) is the annual total marginal sawdust bedding cost ($), \( \text{COST}_F \) is the annual total marginal feed cost ($) from the increase in production, \( \text{COST}_{\text{CL}} \) is the change in labor cost when moving to the new
facility, and \( \text{COST}_{\text{CLT}} \) is the change in lameness cost ($). Equation 4.24 was used to calculate the net annual increase in income:

\[
\text{INCOME}_N = \text{INCOME}_G - \text{COST}_T
\]  
(Eq. 4.24)

Where \( \text{INCOME}_N \) is the net annual increase in income, \( \text{INCOME}_G \) is the gross annual increase in income, and \( \text{COST}_T \) is the annual total increase in costs ($). Equation 4.25 was used to calculate the fixed cost of the barn over the 10 y investment period:

\[
\text{DEP} = \frac{\text{COST}_B}{10}
\]  
(Eq. 4.25)

Where \( \text{DEP} \) is the cost ($) of the investment per y, \( \text{COST}_B \) is the total cost ($) of the barn, and 10 considers the investment period of 10 y. Equation 4.26 was used to calculate annual taxable income:

\[
\text{INCOME}_{\text{TAX}} = \text{INCOME}_G - \text{COST}_T - \text{DEP}
\]  
(Eq. 4.26)

Where \( \text{INCOME}_{\text{TAX}} \) is the taxable income, \( \text{INCOME}_G \) is the gross annual increase in income ($), \( \text{COST}_T \) is the annual total increase in costs ($), and \( \text{DEP} \) is the cost ($) of the investment per y. Annual income tax was calculated using Equation 4.27:

\[
\text{TAX}_I = \text{INCOME}_{\text{TAX}} \times \text{TAX}_R
\]  
(Eq. 4.27)

Where \( \text{TAX}_I \) is the total cost ($) of income tax, \( \text{INCOME}_{\text{TAX}} \) is the taxable income ($), and \( \text{TAX}_R \) is the tax rate (%). Equation 4.28 was used to calculate total annual cash outflow:

\[
\text{OUTFLOW} = \text{COST}_T \times \text{TAX}_I
\]  
(Eq. 4.28)

Where \( \text{OUTFLOW} \) is the total amount of cash ($) paid annually, \( \text{COST}_T \) is the annual total increase in costs ($), and \( \text{TAX}_I \) is the total cost ($) of income tax. Total annual net cash flow was calculated using Equation 4.29:
Where CHF is the net cash flow (\$), CHG is the gross annual increase in income (\$), and OUTFLOW is the total amount of cash (\$) paid annually.

**Financial Parameters.** Financial parameters, including NPV, IRR, breakeven cost (BC), and payback period (PP), were used as a means to determine profitability of a housing system given the input values specified. The NPV was calculated using Equation 4.30:

\[
NPV = \sum_{n=1}^{N} \frac{FLOW}{(1 + DR)^n} - COST_B
\]  

(Eq. 4.30)

Where NPV is the net present value of the given housing investment over the 10 y loan period, FLOW is the net cash flow (\$), DR is the discount rate, n is the production y, and COST_B is the total cost (\$) of the barn. Internal rate of return was calculated using Eq. 4.31:

\[
NPV = \sum_{n=0}^{10} \frac{FLOW_n}{(1 + IRR)^n}
\]  

(Eq. 4.31)

Where NPV is the net present value (\$) of the given housing investment over the 10 y loan period, FLOW is the net cash flow (\$) for a given production y, IRR is the internal rate of return, 10 is the total number of investment y, and n is the production y where n = 0 represents the initial investment cost. Equation 4.32 was used to calculate the BC:

\[
BC = \sum_{n=1}^{10} FLOW_n
\]  

(Eq. 4.32)

Where BC is the breakeven cost (\$) to pay for a barn, FLOW is the net cash flow (\$) for a given production y, and n is the production y. Payback period estimates the
length of time necessary to pay back an investment, taking into account the estimated net income over time. Equation 4.33 was used to calculate the PP:

\[ PP = \frac{\text{COST}_b + \text{COST}_m}{\sum_{n=1}^{10} \text{FLOW}_n} \]  

(Eq. 4.33)

**Sensitivity Analysis**

Sensitivity analyses compared housing facilities under different scenarios. The investment analysis maintained all values at the default assumptions to determine values for each of the financial parameters for each of the systems. Sensitivity analysis 1 held all values at the default except one value, which varied. The varying value was changed using the goal seek function of Excel (Microsoft Excel 2010, Microsoft, Seattle, Washington) until the NPV equaled zero. Varying values included cost of barn per cow space ($ per cow space), milk price ($/kg), feed cost ($/kg DM), milk production increase (kg) after moving into the barn, and cost of bedding ($/d). Sensitivity analysis 2 set lameness prevalence equal to 17.4%, assuming lameness did not change upon moving into a new housing system. Sensitivity analysis 3 set SCC equal to 357,000 cells/mL, assuming no changes in SCC with the transition to a new housing facility. Additionally, SCC was set to 49,000 and 750,000 cells/mL to represent exceptionally low and high SCC, respectively, which may result from a new facility transition. Financial parameters were compared for the three different systems. The fourth analysis compared NPV of each system. A value of interest was varied for one system to produce a NPV equal to a system of comparison.

**Dashboard Interface**
A user-friendly dashboard (http://www2.ca.uky.edu/afsdairy/DairyHousingInvestment) was created using Xcelsius 2008 (SAP® BusinessObjects™, Newtown Square, Pa), a Macromedia Flash™ based software that allows users to interactively change input values to produce subsequent output values. Figure 4.1 displays the dashboard interface and tabbing system. All input values are changeable by the user to suit the particular farm situation. The dashboard uses an easy to navigate, tab organized layout with scroll-over information buttons for additional information on a particular input or output, if necessary. The output layout allows the user to view intermediate revenues and costs, i.e. reduced lameness treatment cost or increased milk production revenue, and the overall NPV, IRR, PP, and BC for each of the three systems. The flexibility of the dashboard allows scenarios outside of CBP, SF, and MF, including other freestall bases, i.e. waterbeds, mats, and deep-bedded sawdust, crushed limestone and recycled manure solids.

RESULTS AND DISCUSSION

Investment Analysis

Both freestall systems resulted in a negative NPV and the CBP barn resulted in a positive NPV (MF: -$109,074; SF: -$97,323; CBP: $23,532; Table 4.2). The CBP resulted in the highest IRR (11%), shortest PP (5.77 y), and BC of $184,041. The SF barn resulted in a higher IRR (0%), shorter PP (10.24), and lower BC ($177,836) compared to the MF (IRR: -1%; PP: 10.45 y; BC: $189,045) (Table 4.2). The higher barn cost of the MF ($1,950 per stall) and SF ($1,800 per stall) created the negative NPV. The CBP barn investment cost is over 40% less ($1,050) than that of the SF and MF. Additionally, lameness was improved for cows housed on the CBP (17.4 to 12.0% from
grazing (Olmos et al., 2009) to CBP (Black et al., 2013)), reducing treatment and decreased fertility costs ($105.93 per case, Cha et al., 2010) by 5.4%. Comparatively, prevalence in SF (19.8%, Cook, 2003) and MF (30.3%, Cook, 2003) increased, increasing treatment and decreased fertility costs by 2.4 and 12.9%, respectively.

Each system increased revenue from elevated milk production (CBP: 2.6 kg; MF: 2.5 kg, SF: 2.5 kg) after moving into the new housing facility. However, revenue increased more in the CBP scenario (Y 1: $46,293; Y 2: $52,465, Y 3 to 10: $61,724 per y) compared to the MF (Y 1: $44,696; Y 2: $50,656; Y 3 to 10: $59,595 per y) and SF (Y 1: $44,696; Y 2: $50,656; Y 3 to 10: $59,595 per y) scenarios because the analysis assumed a higher increase in production from the transition to the CBP barn (2.6 kg, Barberg et al., 2007a) than the MF (2.5 kg, Smith and Ely, 1997) and SF (2.5 kg, Smith and Ely, 1997) barns (Table 4.3). The SCC bonus structure (Table 4.4) requires a SCC less than 250,000 cells/mL to acquire the additional bonus in milk price. The level of change, along with the SCC required to acquire the bonus, varies depending on cooperative and milk buyers. Conversely, producing milk with an elevated SCC causes deductions in milk price, typically when SCC exceeds 400,000 cells/mL. None of the scenarios resulted in increased revenue from the SCC bonus because SCC did not decrease enough to receive the benefit (CBP: 252,859 cells/mL, Black et al., 2012; MF: 357,000 cells/mL, USDA/NAHMS, 2012; SF: 272,000 cells/mL, USDA/NAHMS, 2012).

Housing associated costs increased when moving from pasture to confinement because labor, bedding, and feed requirements increased (Table 4.3). Labor costs increased for the MF ($1,276 per y) and SF ($1,276 per y) systems but remained unchanged for the CBP scenario. Bedding costs increased more for SF barns ($10,050
per y) compared to MF ($7,054 per y) and CBP ($7,430 per y). The entire floor of the CBP must be covered with a minimum of 50 cm of bedding to maintain an active composting environment (Galama et al., 2011) but the composting process combined with natural and mechanical ventilation dries the surface layer of the CBP (Black et al., 2012), possibly reducing bedding needs depending on composting efficiency. Bedding is only necessary in the stall area in MF and SF barns. Recommendations call for 2.5 to 5.1 cm of bedding material covering a MF, and 15.2 cm depth in a deep-bedded SF (MWPS, 2000). However, recommendations are not always followed or different situations may require different bedding amounts (i.e. waterbeds require little to no bedding, bedding retainers), leading to differences in bedding costs.

Feed costs increased for all systems because milk production increased. The CBP scenario assumed the highest level of milk production increase after new facility occupation (CBP: 2.6 kg, Barberg et al., 2007a; MF: 2.5 kg, Smith and Ely, 1997; SF: 2.6 kg, Smith and Ely, 1997) and acquired the greatest increase in feed cost (Y 1: 15,310; Y 2: 17,351; Y 3 to 10: 20,413 per y). Feed costs increased similarly to the CBP in the MF (Y 1: $14,782; Y 2: $16,753; Y 3 to 10: $19,705 per y) and SF (Y 1: $14,782; Y 2: $16,753; Y 3 to 10: $19,705 per y) scenarios. Revenues were greater than costs in all housing systems, implying the benefits of the MF and SF systems were not great enough to meet or exceed the desired DR set (8%, Bewley et al., 2010) for rate of return on the housing investment.

**Sensitivity Analyses**

**Sensitivity Analysis 1.** Market prices of variable costs fluctuate and influence the systems differently depending on the level of associated variable costs. Understanding
how these costs affect potential NPV can prepare the producer for different market scenarios. Reduced barn cost resulted in a NPV of zero for the SF and MF ($1,016 and $1,072 per stall, respectively, Table 4.5). The high investment cost of the MF ($1,950 per stall) and SF ($1,800 per stall) barns outweigh the change in income; however, reducing cost of the barn presents a profitable scenario for the two systems. The CBP scenario allows for an increased barn cost as high as $1,076 per 9.3 m² to obtain a NPV equal to zero; however, a greater cost would lead to a negative NPV. The CBP requires less infrastructure (i.e. stall hardware and concrete) resulting in a reduced cost of the barn ($1,050 per 9.3 m²). Producers would have more flexibility in barn cost per cow, under the default conditions, when constructing a CBP barn compared to a MF and SF barn.

A considerable increase in milk price was necessary to reach a profitable situation for the MF ($0.818 per kg) and SF ($0.569 per kg) barns (Table 4.5). An increase in revenue from milk production would result in greater annual income and an increased IRR at or above the set DR. The CBP scenario could withstand a decrease in milk price while sustaining profitability ($0.415 per kg). Under default conditions, the CBP scenario resulted in a positive NPV, leaving room for a decline in income from increased milk production while still maintaining profitability. Milk prices are volatile and fluctuate depending on milk supply and demand, government policy, supply contracts, production planning, and inventory management (Nicholson and Fiddaman, 2003). This analysis attempted to account for volatility using a 10 y projected milk price (Westhoff et al., 2012).

Feed or bedding costs could increase in the CBP scenario while maintaining a profitable scenario (Feed cost: $0.208 per kg DM; Bedding cost: $0.226 per cow per
The CBP scenario resulted in a positive NPV under default conditions, allowing for increased costs. No positive feed (-$0.377 and -$0.015 per kg DM) or bedding costs (-$45.41 and -$15.87 per d) resulted in a profitable scenario for the MF or SF, respectively (Table 4.5). Though bedding and feed costs affect the outcome of the overall profitability of the housing system, the initial investment was too great to be offset by reduced bedding and feed costs for the MF and SF scenarios. Increased bedding costs could be incurred during inefficient composting conditions of the CBP or overstocking situations in all three systems, requiring more bedding to absorb moisture. Bedding cost is also highly variable depending on region and availability. Additionally, cows may produce more milk than anticipated in any of the housing systems, leading to increased feed cost; however, the additional revenue gained from increased milk production ($0.42 per kg) should offset that of the increased feed intake ($0.20 per kg DM). In scenarios with high feed costs and low milk prices, increased revenue from milk production may not be effective at offsetting the cost of feed, leading to additional costs. In the default scenarios considered for the three systems, only the CBP system could absorb increased feed costs, though only to a limited extent.

No reduction or increase in labor cost resulted in a NPV of zero for the SF (-$30.77 per h) or MF (-$36.52 per h) systems (Table 4.5). A slight $1.85 per h increase from the $10.00 per h (Billikopf, 2009) default resulted in a NPV of zero in the CBP scenario. Labor increased by 21 m/d in both MF and SF housing but did not change in the CBP scenario.

The milk production benefit experienced from moving into the new housing facility would need to increase to 4.1 and 3.9 kg in the MF and SF, respectively, to create
a profitable scenario (Table 4.5). The increase in revenue would increase the IRR for the two systems. However, a lower increase in milk production of 2.6 kg can still support profitability of the CBP system. Nutrition (Beauchemin et al., 2003, Pantoja et al., 1994, Rhoads et al., 2009), genetics (Georges et al., 1995, Riquet et al., 1999, Schutz et al., 1994), and environment (Breuer et al., 2000, Hahn and Osburn, 1970, Haskell et al., 2006) all influence milk production. Changes in any of these factors can influence milk production and overall revenue from milk production.

**Sensitivity Analysis 2.** Lameness prevalence can change in a new housing system similar to cost incurred from management. Several studies have documented lameness incidence in freestall herds. Cook (2003) discovered lower mean lameness prevalence (locomotion scale of 1 to 4, where 1 is sound and 4 is severely lame; prevalence calculated as percent cows scored with locomotion score ≥ 3) among herds with SF (summer prevalence: 18.4%; winter prevalence: 21.2%) compared to herds with non-SF (summer prevalence: 26.8%; winter prevalence: 33.7%). High milk production cows are more prone to lameness (lameness diagnosed by producer; Green et al., 2002) due to exposure to high stress from milk production, which can create adverse hoof health issues (Espejo et al., 2006). A survey of high production Holstein cows in Minnesota determined a mean lameness prevalence (locomotion scale of 1 to 5, where 1 is sound and 5 is severely lame; prevalence calculated as percent cows scored with locomotion score ≥ 3) of 24.6%, where cows housed in SF barns presented lower lameness prevalence than those in MF (17.1 vs. 27.9%) (Espejo et al., 2006). The increase in traction and cushion that sand offers may be an explanation to the improved hoof health of cows housed in SF barns compared to MF barns (Vokey et al., 2001).
Compost bedded pack barns avoid many issues causing lameness observed in freestall barns. The pack is free of concrete alleys and cows walk and stand on compost (Barberg et al., 2007a). Cook (2008) noted that cows spend an average of 14 h in the pen area after eating, drinking, and milking times are accounted for, therefore, for those 14 h, cows are standing or lying on a softer surface. Lobeck et al. (2011) conducted a study observing the animal welfare in CBP barns, CV barns, and NV freestall barns discovering lower lameness incidence in CBP barns (4.4%) compared with the CV (13.1%) and NV (15.9%) barns. An earlier study conducted by Barberg et al. (2007b) observed similar results, where 7.8% of cows housed on the CBP exhibited clinical lameness. Researchers further hypothesized that this prevalence may still be associated with previous injuries from prior housing. Producers participating in the study indicated that cows stayed in the herd longer due to improved ability to stand up and lie down on the CBP. Shane et al. (2010) investigated alternative bedding materials for CBP barns and observed a seasonal difference where lameness prevalence was 9.1% in the fall, 12.1% in the spring, 12.2% in the summer, and 13% in the winter. On average, lame cows constituted 9.1% of the herd while severely lame cows made up 2.5% of the herd.

Even when lameness prevalence was assumed to stay consistent when moving from a grazing system to an indoor housing system, NPV remained negative for the freestall systems and became negative for the CBP barn (MF: -$95,574, SF: -$93,262; CBP: -$1,001). The amount of change, however, differed between the systems. For the MF, with an assumed 12.9% increase in lameness prevalence, NPV changed by $64,885. However, an assumption of smaller changes in the CBP (-5.4%) and SF (2.4%) resulted in smaller changes in NPV (-$4,137 and $1,859, respectively). Farms with higher
lameness prevalence will benefit more from new dairy housing than those with lower prevalence because there is more to gain in cost savings.

**Sensitivity Analysis 3.** Udder health, as indicated by SCC, can change when transitioning from a grazing dairy system to an indoor housing facility. Fontaneli et al. (2005) reported higher SCC in freestall managed herds (654,000 cells/mL) compared to grazing herds (223,000 and 364,000 cells/mL) in Florida while Smith and Ely (1997) reported lower SCC in freestall herds (102,000 cells/mL) compared to grazing herds (180,000 cells/mL). The USDA/NAHMS (2012) reported higher SCC in MF barns (357,000 cells/mL) and grazing herds (357,000 cells/mL) compared to SF barns (272,000 cells/mL). Udder health, indicated by SCC, improved in a study by Barberg et al. (2007b), where estimated mastitis infection rate (cows with SCC ≥ 200,000 cells/mL divided by the total number of animals) reduced from 35.4% to 27.7% after moving into the CBP barn. Additionally, farms reported a mean SCC of 325,000 cells/mL, a value lower than the Minnesota state average. Researchers studying cow welfare differences between housing systems determined no statistical difference between mastitis incidence (cows with SCC ≥ 200,000 cells/mL divided by the total number of animals) between CV, NV, and CBP barns (26.8%, 26.8%, and 33.4%, respectively) (Lobeck et al., 2011). Kentucky dairy herds transitioning from a pasture-based system or outdated freestall barn to CBP barn, used as the primary housing facility, experienced a decrease in bulk tank SCC (Black et al., 2012). Somatic cell count decreased from 323,692 ± 7,301 cells/mL in the y before moving into the CBP barn to 252,859 ± 7,112 cells/mL in the y after moving into the CBP barn.
Assuming no changes in SCC when moving into a new system, no changes in NPV, IRR, PP, or BC resulted compared to values produced using default values (Table 4.4) for any of the three systems. The default SCC was not low enough to obtain the benefits of the SCC bonus, where additional revenue is earned for milk with a SCC less than 250,000 cells/mL. However, no deductions were imposed because SCC was not above 400,000 cells/mL. The lack of change in economic viability resulting from the default scenario compared to a scenario with no changes in SCC implies that the SCC bonus structure plays little role in the decisions of new dairy housing when considering the default scenarios.

Management in the parlor (Barkema et al., 1998a, Haskell et al., 2009) and of lying surfaces (Zdanowicz et al., 2004) can influence SCC. Therefore, producers moving into a new housing facility may experience different SCC due to management of the system. Cows moving from a pasture-based system into housing are expected to experience reduced SCC due to a higher degree of management for cow needs. However, cows transitioning from a freestall barn to a CBP barn may also experience a reduction in SCC (D. Davis and B. Crist, personal communication). Financial parameters improve when SCC decreases to 49,000 cells/mL because producers receive the maximum bonus level ($0.50/kg when SCC < 50,000 cells/mL). However, the SF (NPV: -$31,677.19, IRR: 5%, PP: 7.49 y, BC: $243,481.61) and MF (NPV: -$43,428.17, IRR: 5%, PP: 7.77 y, BC: $254,660.53) barns still remain below the level of investment profitability set as acceptable even with an increase in revenue from the SCC bonus (MF – Y 1: $12,173.63, Y 2: $14,312.00, Y 3 to 10: $14,476.15 per y; SF – Y 1: $12,173.63, Y 2: $14,312.00, Y 3 to 10: $14,476.15 per y). Financial parameters (NPV: $89,225.16, IRR: 19%, PP: 4.26
Poorly managed housing systems can result in increased SCC. The current legal SCC limit is 750,000 cells/mL (FDA, 2009). Milk produced with a SCC higher than the limit will result in violations, penalties, and, in some cases, suspension of the producer’s permit. Milk buyers and cooperatives will often times set milk price penalties for SCC greater than 400,000 cells/mL. When the SCC is elevated to 750,000 cells/mL, all scenarios resulted in negative financial parameters below that set as acceptable (DR < 8%). The MF barn resulted in lower NPV (-$156,542.27), lower IRR (-5%), higher PP (13.90 y), and higher BC ($141,546.43) than the CBP (NPV: -$23,792.26, IRR: 5%, PP: 7.73 y, BC: $136,869.91) or SF (NPV: -$144,741.20, IRR: -5%, PP: 13.89 y, BC: $130,417.60) barns.

**Model Limitations**

Some aspects of change when moving into the three housing systems were not included in the model because of a lack of information. These changes included clinical mastitis incidence, manure storage and handling costs, cow longevity, and herd reproductive performance. Clinical mastitis can be a costly disease, with estimates ranging from $179 (Bar et al., 2008) to $349.39 per case (Kossaibati and Esslemont, 1997). Clinical mastitis incidence has been documented in freestall, tie stall, and conventional bedded pack herds, with varying results between studies. Olde Riekerink et al. (2008) determined an incidence of 26.6 cases per 100 cow-y (number of mastitis cases per 36,500 d at risk) in tie stall barns and 19.1 cases per 100 cow-y in freestall barns in Canada. However, Berry (1998) reported that producers housing cows on a
conventional bedded pack observed a mean clinical mastitis incidence of 38 cases per 100 cow-y. No clinical mastitis research has been conducted for cows housed in a CBP barn to determine incidence rates experienced in the system. The bedded pack and CBP barns have similarities in concept and design, but the lying surface of cows housed on the CBP may be drier and a better suited lying surface to reduce clinical mastitis incidence. However, no assumptions of clinical mastitis were made in this model and all systems were considered to have equal clinical mastitis prevalence before and after moving into new housing facilities. Many producers and researchers predict and increase in clinical mastitis incidence when cows are housed on the CBP, but this may happen with any mismanaged housing system. No research evidence is available to indicate a difference in clinical mastitis incidence between the CBP barn system and freestall systems.

A secondary benefit of the CBP barn is the reduced manure storage requirement compared to freestall housing because the CBP acts as manure storage, requiring less liquid manure storage. Producers typically remove the bedding material from the CBP barn 1.7 ± 0.8 times per y (Black et al., 2012). Additionally, liquid storage, depending on the size, will last for a longer period due to reduced amount of manure and urine in the alleyways. Manure storage typically lasts for 180 d (USEPA/OST, 2001) when all manure goes into liquid manure store, typical in a freestall system, creating a need for more frequent cleanout. Sand freestall housing requires additional manure handling investment compared to MF housing and CBP housing. Sand requires additional equipment (i.e. mechanical manure separator) and creates more wear on equipment from sand grinding equipment parts resulting in a reduced useful life. The solid state of the CBP material allows for easier transport and likely easier handling. A manure spreader
can transport and spread material onto the fields without many of the concerns of liquid manure handling. Additionally, when dealing with well-composted material, material amount should decrease with time and odor should be minimal. Manure handling costs were not included in this model because of lack of information on the true costs and benefits associated with the manure management system in the CBP. Though the system is proposed to decrease costs, no literature is available to support these claims. Therefore, manure management systems are considered equivalent in this analysis.

Cow longevity can be influenced by a cow’s genetic makeup and environment (Parker et al., 1960). Genetic selection for production does not typically improve cow longevity (Haile-Mariam et al., 2003). However, housing may influence cow longevity, particularly related to bedding amount in freestalls (Buenger et al., 2001). Cows housed with no bedding had higher risk of culling compared to those with adequate bedding. Black et al. (2012) reported that ten producers built a CBP to house heifers, lame, problem, old, and fresh cows, while eight producers anticipated improved feet and legs. Three producers chose to build a CBP for increased longevity of cows within the herd. This may have implications related to the CBP barn because the system provides a soft, comfortable lying surface for cows, influencing lying times (Eckelkamp et al., 2013) and lameness (Black et al., 2012). However, little research has been conducted on these comfort assessments and little can be inferred regarding their implications on the longevity of cows housed on the CBP. Therefore, cow longevity was not included in this model.

Similar to clinical mastitis and cow longevity, few researchers have reported the effects on reproductive performance of cows housed in the CBP barn (Barberg et al.,
Producers proposed improved estrus expression behavior because of better footing on the CBP compared to concrete, similar to that in the conventional bedded pack barn (Phillips and Schofield, 1994). However, due to the differences in the two systems concerning management and cow health, few comparisons can be drawn. Reproductive performance was excluded from this model because research on the subject was too sparse.

Compost bedded pack barns are a relatively new concept (first barn built in 2002) and producers managing these systems are still considered early adopters. Freestall barns originated in the mid 1900’s and are accompanied by a vast field of knowledge on management and design. Relatively little research explains design and management of the CBP barn system, creating a greater risk for producers deciding to use the housing facility. Additionally, though the management tasks are simple in concept, producers must manage the system persistently, because more risk can be associated with the system failing compared to a freestall barn. Producers deciding to manage the CBP system should understand the risk acquired when constructing this new facility.

**CONCLUSIONS**

Market cost variability affects the long-term profitability of investment decisions and considering those costs before making a decision can better the chance of a successful investment. Compost bedded pack barns resulted in greater investment profitability compared to the MF and SF barns due to reduced barn costs and increased daily milk production from transitioning to the new housing facility. Increased milk production due to the transition to the new facility, increased milk price, or reduced building investment cost may make the MF and SF barns more profitable investment
decisions. Improved lameness prevalence and SCC affect the investment decisions only slightly when considering the MF and SF barns in the default scenarios. However, the CBP barn scenario becomes a less profitable scenario when lameness prevalence and SCC are high. The results were most sensitive to fixed investment cost per cow and bedding costs. Using the New Dairy Housing Investment Analysis Dashboard allows users an interactive and flexible decision tool to make more informed facility investment decisions.

ACKNOWLEDGEMENTS

The authors would like to thank the participating producers for their cooperation in this study and Bob Klingensfus and David Corbin for their continual advice and expertise. Additionally, we extend our gratitude to Drs. Joseph Taraba and George Day for their stimulating conversation and intellectual contributions to this work.
Table 4.1. Default inputs for herd parameters of four management systems: pasture, mattress base freestall barn, sand base freestall barn, and compost bedded pack barn.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current housing situation – Herd and management characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herd size (including lactating and dry cows)</td>
<td>179</td>
<td>USDA/NASS, 2012</td>
</tr>
<tr>
<td>Percent herd in milk (%)</td>
<td>85.4</td>
<td>Dairy Metrics (Dairy Records Management System, Raleigh, NC, June 2012)</td>
</tr>
<tr>
<td>Rolling herd average milk yield (kg)</td>
<td>9,682</td>
<td>USDA/NASS, 2012</td>
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<tr>
<td>Milk fat (%)</td>
<td>3.6</td>
<td>Dairy Metrics (Dairy Records Management System, Raleigh, NC, June 2012)</td>
</tr>
<tr>
<td>Feed efficiency ratio¹ (kg milk/kg DM)</td>
<td>1.36</td>
<td>Casper et al., 2004</td>
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<tr>
<td>SCC on pasture (cells/mL)</td>
<td>357,000</td>
<td>USDA/NAHMS, 2012</td>
</tr>
<tr>
<td>Clinical lameness prevalence (%)</td>
<td>17.4</td>
<td>Olmos, 2009</td>
</tr>
<tr>
<td>Number of times milked per d</td>
<td>2</td>
<td>Model assumption</td>
</tr>
<tr>
<td>Time spent moving cows to holding pen (min)</td>
<td>30</td>
<td>R Klingensfus and D Corbin, personal communication</td>
</tr>
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</table>
Table 4.1. cont.

Current housing situation – Financial values

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<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Source</th>
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<tbody>
<tr>
<td>Long-term milk price ($/kg)</td>
<td>0.42</td>
<td>Westhoff et al., 2012</td>
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<tr>
<td>Lactating cow feed cost ($/kg DM)</td>
<td>0.20</td>
<td>Bailey and Ishler, 2007; FAPRI, 2012</td>
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<td>Labor cost ($/h)</td>
<td>10.00</td>
<td>Billikopf, 2009</td>
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<tr>
<td>Discount rate (%)</td>
<td>8.00</td>
<td>Bewley et al., 2010</td>
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<tr>
<td>Interest rate (%)</td>
<td>6.0</td>
<td>K Burdine, personal communication</td>
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<tr>
<td>Tax rate (%)</td>
<td>30.8</td>
<td>C Dillon, personal communication</td>
</tr>
<tr>
<td>Length of loan (y)</td>
<td>10</td>
<td>Model assumption</td>
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<tr>
<td>Cost of clinical lameness(^2) ($/case)</td>
<td>105.93</td>
<td>Cha et al., 2010</td>
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</table>

Mattress freestall barn scenario

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<tr>
<th>Description</th>
<th>Value</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>Cost of barn per stall ($)</td>
<td>1,950</td>
<td>Horner et al., 2007</td>
</tr>
<tr>
<td>Cost of sawdust bedding ($/m(^3))</td>
<td>6.53</td>
<td>Black et al., 2013</td>
</tr>
<tr>
<td>Amount bedding added per d (m(^3))</td>
<td>2.75</td>
<td>Black et al., 2013</td>
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<td>Predicted time bringing cows to holding pen (min)</td>
<td>15</td>
<td>R Klingenberg and D Corbin, personal communication</td>
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<tr>
<td>Number of times rake stalls (times/d)</td>
<td>2</td>
<td>Model assumption – during milking</td>
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<tr>
<td>Predicted time to rake stalls (s/stall)</td>
<td>10</td>
<td>R Klingenberg and D Corbin, personal communication</td>
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Table 4.1. cont.

<table>
<thead>
<tr>
<th>Description</th>
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<th>Source</th>
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<tr>
<td>Predicted daily increase in production per cow (kg)</td>
<td>2.5</td>
<td>Smith and Ely, 1997</td>
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<tr>
<td>Predicted SCC (cells/mL)</td>
<td>357,000</td>
<td>USDA/NAHMS, 2012</td>
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<tr>
<td>Predicted lameness prevalence (%)</td>
<td>30.3</td>
<td>Cook, 2003</td>
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<td>Sand freestall barn scenario</td>
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<tr>
<td>Cost of barn per stall ($)</td>
<td>1,800</td>
<td>Horner et al., 2007</td>
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<tr>
<td>Cost of sand bedding per ton ($/kg)</td>
<td>0.099</td>
<td>Buli et al., 2010</td>
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<tr>
<td>Amount of bedding added per stall (kg/stall/d)</td>
<td>18.2</td>
<td>Gooch et al., 2003</td>
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<tr>
<td>Predicted time to bring cows to holding pen (min)</td>
<td>15</td>
<td>R Klingenfus and D Corbin, personal</td>
</tr>
<tr>
<td>Number of times rake stalls per d</td>
<td>2</td>
<td>Model assumption – during milking</td>
</tr>
<tr>
<td>Predicted time to rake stalls (s/stall)</td>
<td>10</td>
<td>Producers, personal communication</td>
</tr>
<tr>
<td>Predicted daily increase in production per cow (kg)</td>
<td>2.5</td>
<td>Smith and Ely, 1997</td>
</tr>
<tr>
<td>Predicted SCC (cells/mL)</td>
<td>272,000</td>
<td>USDA/NAHMS, 2012</td>
</tr>
<tr>
<td>Predicted clinical lameness prevalence (%)</td>
<td>19.8</td>
<td>Cook, 2003</td>
</tr>
<tr>
<td>Compost bedded pack barn scenario</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost of barn per cow space ($/ 9.3 m )</td>
<td>854.55</td>
<td>Black et al., 2013</td>
</tr>
</tbody>
</table>
Table 4.1. cont.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of sawdust bedding ($/m^3)</td>
<td>6.53</td>
<td>Black et al., 2013</td>
</tr>
<tr>
<td>Amount bedding per d (m^3)</td>
<td>4.91</td>
<td>Black et al., 2013</td>
</tr>
<tr>
<td>Predicted time to bring cows to holding pen (min)</td>
<td>15</td>
<td>R Klingenfus and D Corbin, personal communication</td>
</tr>
<tr>
<td>Predicted daily increase in production per cow (kg)</td>
<td>2.6</td>
<td>Barberg et al., 2007a</td>
</tr>
<tr>
<td>Predicted SCC (cells/mL)</td>
<td>252,860</td>
<td>Black et al., 2013</td>
</tr>
<tr>
<td>Predicted clinical lameness prevalence (%)</td>
<td>12.0</td>
<td>Black et al., 2013</td>
</tr>
</tbody>
</table>

1Feed efficiency ratio reported by Casper et al. (2004) was 1.47 for 3.5% fat-corrected milk. Ratio was converted to 4% fat-corrected milk using equation specified by NRC (2001).

2Clinical lameness case cost does not account for reduced milk production but includes treatment cost and decreased fertility.

3Production increase from moving into new housing facility.
Table 4.2. Net present value, internal rate of return, payback period, and breakeven barn cost for compost bedded pack barn, mattress base freestall barn, and sand base freestall barn with all input values maintained at defaults.

<table>
<thead>
<tr>
<th>Financial Parameter</th>
<th>Housing System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compost bedded pack barn</td>
</tr>
<tr>
<td>Net present value ($)</td>
<td>23,532</td>
</tr>
<tr>
<td>Internal rate of return (%)</td>
<td>11</td>
</tr>
<tr>
<td>Payback period (y)</td>
<td>5.77</td>
</tr>
<tr>
<td>Breakeven barn cost ($)</td>
<td>184,041</td>
</tr>
</tbody>
</table>
Table 4.3. Intermediate costs and revenues gained from additional costs, improved lameness, and udder health acquired from a new dairy housing facility.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Compost bedded pack barn</td>
<td></td>
</tr>
<tr>
<td>Annual milk yield revenue change ($)</td>
<td>46,293 52,465 61,724 61,724 61,724 61,724 61,724 61,724 61,724 61,724</td>
</tr>
<tr>
<td>Annual SCC bonus revenue change ($)</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Annual lameness treatment cost change ($)</td>
<td>-656 -743 -874 -874 -874 -874 -874 -874 -874 -874</td>
</tr>
<tr>
<td>Annual labor cost change ($)</td>
<td>0 0 0 0 0 0 0 0 0 0</td>
</tr>
<tr>
<td>Annual feed cost change ($)</td>
<td>15,310 17,351 20,413 20,413 20,413 20,413 20,413 20,413 20,413 20,413</td>
</tr>
<tr>
<td>Annual bedding cost change ($)</td>
<td>7,430 7,430 7,430 7,430 7,430 7,430 7,430 7,430 7,430 7,430</td>
</tr>
<tr>
<td>Net annual income change ($)</td>
<td>24,209 28,427 34,755 34,755 34,755 34,755 34,755 34,755 34,755 34,755</td>
</tr>
</tbody>
</table>
Table 4.3. cont.

Mattress base freestall

<table>
<thead>
<tr>
<th></th>
<th>Annual milk yield revenue</th>
<th>Annual SCC bonus revenue</th>
<th>Annual lameness treatment cost</th>
<th>Annual labor cost change ($)</th>
<th>Annual feed cost change ($)</th>
<th>Annual bedding cost change ($)</th>
<th>Net annual income change ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44,696</td>
<td>0</td>
<td>1,567</td>
<td>1,276</td>
<td>14,782</td>
<td>7,054</td>
<td>20,018</td>
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<td></td>
<td>50,656</td>
<td>0</td>
<td>1,776</td>
<td>1,276</td>
<td>16,753</td>
<td>7,054</td>
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<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
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<tr>
<td></td>
<td>59,595</td>
<td>0</td>
<td>2,089</td>
<td>1,276</td>
<td>19,705</td>
<td>7,054</td>
<td>29,467</td>
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</tbody>
</table>

Sand base freestall

<table>
<thead>
<tr>
<th></th>
<th>Annual milk yield revenue</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Net annual income change ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>44,696</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20,018</td>
</tr>
<tr>
<td></td>
<td>50,656</td>
<td></td>
<td></td>
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<td></td>
<td>23,798</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td></td>
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<td></td>
<td>29,467</td>
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<tr>
<td></td>
<td>59,595</td>
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<td>29,467</td>
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<td></td>
<td>59,595</td>
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<td></td>
<td>29,467</td>
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<tr>
<td></td>
<td>59,595</td>
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<td></td>
<td></td>
<td></td>
<td>29,467</td>
</tr>
<tr>
<td></td>
<td>59,595</td>
<td></td>
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<td>29,467</td>
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<td>59,595</td>
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<td></td>
<td></td>
<td></td>
<td>29,467</td>
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</tbody>
</table>
Table 4.3. cont.

<p>| | | | | | | | | | | | |</p>
<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual SCC bonus revenue</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Annual lameness treatment cost</td>
<td>292</td>
<td>330</td>
<td>389</td>
<td>389</td>
<td>389</td>
<td>389</td>
<td>389</td>
<td>389</td>
<td>389</td>
<td>389</td>
<td>389</td>
</tr>
<tr>
<td>Annual labor cost change ($)</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
<td>1,276</td>
</tr>
<tr>
<td>Annual feed cost change ($)</td>
<td>14,782</td>
<td>16,753</td>
<td>19,705</td>
<td>19,705</td>
<td>19,705</td>
<td>19,705</td>
<td>19,705</td>
<td>19,705</td>
<td>19,705</td>
<td>19,705</td>
<td>19,705</td>
</tr>
<tr>
<td>Annual bedding cost change ($)</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
<td>10,050</td>
</tr>
</tbody>
</table>

\(^1\)Production year after moving into a new dairy housing facility. The model assumes cow health improves by 75% of the predicted improvement amount, 85% in the second year, and 100% in the third and proceeding years.
Table 4.4. Somatic cell count bonus structure for increased or reduced milk price when herd level somatic cell count is within a certain range (Anonymous Cooperative Representative, Personal Communication).

<table>
<thead>
<tr>
<th>SCC (cells/mL)</th>
<th>Bonus Amount ($/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 400,000</td>
<td>-0.001136</td>
</tr>
<tr>
<td>376,000 to 400,000</td>
<td>0</td>
</tr>
<tr>
<td>351,000 to 357,000</td>
<td>0</td>
</tr>
<tr>
<td>326,000 to 350,000</td>
<td>0</td>
</tr>
<tr>
<td>301,000 to 325,000</td>
<td>0</td>
</tr>
<tr>
<td>276,000 to 300,000</td>
<td>0</td>
</tr>
<tr>
<td>251,000 to 275,000</td>
<td>0</td>
</tr>
<tr>
<td>226,000 to 250,000</td>
<td>0.000909</td>
</tr>
<tr>
<td>201,000 to 225,000</td>
<td>0.000909</td>
</tr>
<tr>
<td>176,000 to 200,000</td>
<td>0.001363</td>
</tr>
<tr>
<td>151,000 to 175,000</td>
<td>0.001363</td>
</tr>
<tr>
<td>126,000 to 150,000</td>
<td>0.001363</td>
</tr>
<tr>
<td>101,000 to 125,000</td>
<td>0.001591</td>
</tr>
<tr>
<td>76,000 to 100,000</td>
<td>0.001591</td>
</tr>
<tr>
<td>51,000 to 75,000</td>
<td>0.001591</td>
</tr>
<tr>
<td>26,000 to 50,000</td>
<td>0.001591</td>
</tr>
<tr>
<td>≥ 25,000</td>
<td>0.001591</td>
</tr>
</tbody>
</table>
Table 4.5. Input values necessary to produce a net present value of zero for a compost bedded pack barn, mattress base freestall barn, and sand base freestall barn.

<table>
<thead>
<tr>
<th>Input value</th>
<th>Housing system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compost bedded pack barn</td>
</tr>
<tr>
<td>Cost of barn(^1) ($/cow space)</td>
<td>1,244.04</td>
</tr>
<tr>
<td>Milk price ($/kg)</td>
<td>0.383</td>
</tr>
<tr>
<td>Cost of bedding ($/d)</td>
<td>34.22</td>
</tr>
<tr>
<td>Feed price ($/kg DM)</td>
<td>0.253</td>
</tr>
<tr>
<td>Milk production increase(^2) (kg)</td>
<td>2.3</td>
</tr>
</tbody>
</table>

\(^1\)Cost of barn in terms of cow space. Compost bedded pack barn = $/9.3 m\(^2\); Freestall barn = $/stall

\(^2\)Milk production increase resulting from housing cows in new housing facility.
Figure 4.1. New Dairy Housing Investment Dashboard interface.
APPENDIX

Figure A2.1. Producer survey to assess management practices employed on 42 compost bedded pack barns in Kentucky.

Barn Characteristics

Move in date: ____________________________________________

Previous Housing: ________________________________________

Who was the contractor/builder: ____________________________

Most important influence on barn design: ____________________

Pack Characteristics

Bedding type: ____________________________________________

Frequency of new bedding addition: _________________________

Amount of bedding added per addition: ______________________

Cleanout frequency: _____________________________________

Amount of CBP left at cleanout: _____________________________

Amount of shavings added to begin new CBP: _______________

Depth of CBP at cleanout: _________________________________

Reasons for bedding addition: ______________________________
Figure A2.1 cont.

Days since last bedding addition: ____________________________________________________________

Times stir CBP per day: ________________________________________________________________

Depth of CBP stirring: ________________________________________________________________

Type of stirring equipment: Cultivator  Rototiller  Push  Pull

Economics

Total cost of building: _________________________________________________________________

Amount of construction completed by producer: __________________________________________

Barn: New  Retrofit

Amount spent on bedding: ___________________________________________________________

Distance traveled for bedding: _________________________________________________________

Parlor

Type of parlor: ________________________________________________________________

Times milk per day: ________________________________________________________________

Milking procedures:

Use gloves: Yes  No
**Figure A2.1 cont.**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-dip:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dry teats before attach milker:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Individual towels for each cow:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Automatic takeoffs:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Post-dip:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Posted milking procedures:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Culture milk samples:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Analyze milk system annually:</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dry treat all quarters at dry off:</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

**Farmer Comments**

- Satisfied with barn: _____________________________________________________________
- Aspects would change: __________________________________________________________
- Aspects like: _________________________________________________________________
- Recommendations to other farmers: _____________________________________________
- Lessons learned: _____________________________________________________________
Figure A2.1 cont.

Manure Management

Frequency scrape feed alley: __________________________________________________________

Equipment used to scrap alleyways: __________________________________________________

Lagoon: Yes No

DHIA Supplement

Permission to access DHIA: Yes No

Who sell milk to: ________________________________________________________________

Access historical SCC: Yes No

Voluntary waiting period: _________________________________________________________

Milk fat %: ________________________________

Protein %: ________________________________

Average dairy milk production: ___________________________________________________

Actual SCC: _________________________________________________________________

Cull rate: ________________________________________________________________

Reasons cows left herd: ________________________________________________________
REFERENCES


Bailey, K., and V. Ishler. 2007. Tracking milk prices and feed costs. Department of Agricultural Economics and Rural Sociology. Penn State University, Park City, PA.


Kammel, D. W. 2004. Design and maintenance of a bedded pen (pack) housing system. in Proc. 2004 Midwest Herd Health Conference, Eau Claire, WI. University of Wisconsin, Madison, WI.


McFarland, D. F. 2003. Freestall design: Cow recommended refinements. Pages 131-138 in Proc. 5th International Dairy Housing Conference, Fort Worth, TX. ASAE, St. Joseph, MI.


Policy Research Institute, College of Agriculture, Food and Natural Resources, University of Missouri.


VITA

Randi Black was born on September 11th, 1987 in Lexington, KY. Randi graduated from Woodford County High School in 2005 and continued her education at the University of Kentucky to pursue a degree in Animal Science. She obtained her Bachelor’s of Science degree in Animal Science in 2009. During her undergraduate years, Randi worked as a veterinary technician at Hagyard Equine Medical Institute and was awarded the KEEP Scholarship in 2007. Randi also participated in Dairy Challenge, where her interest in dairy cattle was sparked.

In fall of 2010, Randi began studying for her Master’s of Science under the direction of Dr. Jeffrey Bewley studying the effect of compost bedded pack barns on cow performance. Randi presented her research findings at the 2011 Joint Annual ADSA-AMPA-ASAS-CSAS-WSASAS Meeting in New Orleans, LA and the 2012 Joint Annual ADSA-AMPA-ASAS-CSAS-WSASAS Meeting in Phoenix, AZ. Randi also presented her findings at the 2012 Dairy Cattle Welfare Symposium in Guelph, Ontario, Canada. Randi conducted two additional research projects; one examining the changes in cortisol level in dairy cattle when given access to a rotating cow brush, and one validating the accuracy of a RTLS to track the position of dairy cattle inside a barn. Results from these studies were presented at the 2012 Joint Annual ADSA-AMPA-ASAS-CSAS-WSASAS Meeting in Phoenix, AZ. Outside of research, Randi acted as a teaching assistant in the Animal Production Principles and Agricultural Management Principles courses. She also served as the co-founder and media chair in the University of Kentucky Animal and Food Sciences Graduate Association.
Scientific Meeting Abstracts:


