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

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ABSTRACT

The objective of the research was to characterize herd performance, producer satisfaction and recommendations, and management practices used by compost bedded pack (CBP) managers in Kentucky (42 farms and 47 CBP facilities). Farms were visited between October 2010 and March 2011. A random selection of cows housed solely in the CBP were scored for locomotion and hygiene. Changes in monthly Dairy Herd Improvement Association performance records, including milk production, SCC, reproductive performance, and daily bulk-tank somatic cell count after moving into the CBP were analyzed using the MIXED procedure of SAS (SAS 9.3; SAS Institute Inc., Cary, NC). The GLM procedure of SAS (SAS 9.3) was used to develop models to describe CBP moisture, CBP temperature at 20.3 cm, and mean herd hygiene. Producers provided 9.0 ± 2.2 m² of pack space per cow (n = 44). Barns constructed with an attached feed alley cost $1,051 ± 407 per cow (n = 40). Barns constructed without an attached feed alley cost $493 ± 196 per cow (n = 13). Kiln-dried shavings required 0.05 ± 0.04 m³ of bedding per cow per day (n = 15). Green shavings required 0.07 ± 0.06 m³ of bedding per cow per day (n = 12). The most-frequently cited benefits of the CBP included cow comfort (n = 28), cow cleanliness (n = 14), and the low-maintenance nature of the system (n = 10). Increased stirring frequency, stirring depth, and ambient temperature increased pack temperature, measured at 20.3 cm below the CBP surface. Increased stirring depth, pasture-adjusted space per cow, and drying rate decreased CBP moisture. Mean herd locomotion and hygiene scores were 1.5 ± 0.3 (n = 34) and 2.2 ± 0.4 (n = 34), respectively. Increased 20.3-cm depth CBP temperature and ambient temperatures improved mean herd hygiene. Bulk-tank somatic cell count decreased from the year before to the year after moving into the CBP barn (323,692 ± 7,301 vs. 252,859 ± 7,112 cells/mL, respectively) for farms using the CBP barn as the primary housing facility (n = 9). Daily milk production, collected from monthly Dairy Herd Improvement Association tests, increased from before moving into the CBP barn to the second year after (29.3 ± 0.3 vs. 30.7 ± 0.3 kg, respectively) for farms using the CBP barn as the primary housing facility (n = 8). Calving interval decreased from the year before to the second year after (14.3 ± 0.1 vs. 13.7 ± 0.1 mo) moving into the CBP barn for farms using the CBP as primary housing (n = 8).

Key words: compost bedded pack barn, facility management

INTRODUCTION

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 conventional bedded packs. 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 6 to 12 mo (Janni et al., 2007). Temperature is a key composting efficiency measure (Imbeah, 1998). Active compost material aeration supports microbial heat production. Milking typically occurs 2 times per day, 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°C) promote pathogen destruction (Stentiford, 1996), which may be advantageous for mastitis-causing bacteria reduction. However, CBP temperatures observed by Barberg et al. (2007a) 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.
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 feed bunk or waterer (Janni et al., 2007). 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). 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 with 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) observed 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 (13.1%; P = 0.01) and naturally ventilated (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 with 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; Schreiner and Ruegg, 2003; Reneau et al., 2005). 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 6 CBP barns. A study comparing CBP barns, cross-ventilated barns, and naturally ventilated 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 cross-ventilated (2.83) and naturally ventilated (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, 214,000, and 229,000 cells/mL for the 3 Israeli CBP barns without additional bedding added.

The primary objective of this study was to define key management strategies used by Kentucky farmers operating CBP barns and CBP influences on cow udder health and hygiene, lameness, milk yield, and reproductive 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. University of Kentucky county extension agents and Kentucky Dairy Development Council (Lexington) consultants identified farms operating CBP barns. Agents and consultants identified 58 farms, with 42 agreeing to participate. Five of the participating farms operated 2 CBP barns, presenting 47 CBP to sample. Each farm was visited once during the study period, with 2 to 3 visits per collection day. Data collection occurred at different times of the day for each farm according to site visit schedule and availability. 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 questionnaire was used to assess management practices by interviewing the producer and asking a series of questions during the site visit. All management practices, including stirring depth, stirring frequency, pasture access, and bedding type and addition frequency were subjective answers from the producer and not measured by researchers. Monthly 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. Fifteen 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 \((n = 34)\) at the time of the site visit. 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 \((e.g., \text{even number, odd number, or multiple of } 3)\) and scored for both locomotion and hygiene by the same observer at each farm visit.

Lameness was assessed by observing cows walking on concrete and 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 \(\geq 3\) were classified as clinically lame. Hygiene was evaluated using a system ranging from \(1\) to \(4\), where \(1 = \) clean and \(4 = \) filthy \((Cook \ and \ Reinemann, \ 2007)\), scoring the udder and hind legs for cleanliness. Mean herd hygiene was calculated for use in further analysis.

**Compost Nutrient Analysis.** Bedding material samples were collected from 9 evenly distributed locations throughout each barn at the time of the site visit. Compost bedded packs were sampled at varying stages of degradation and material level. Researchers collected 118.3 cm\(^3\) of surface layer bedding material from each location \((\text{total of } 1,064.7 \text{ cm}^3)\), using a 59.1-cm\(^3\) measuring cup \((\text{Everyday Living; The Kroger Co., Cincinnati, OH})\) in a 3.8-L plastic bag \((\text{Ziploc, Slider Storage and Freezer Bags with Smart Zip Seal; S. C. Johnson \& Son Inc., Racine, WI})\) 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 \((\text{Lexington})\) laboratory personnel on all bedding material samples to determine moisture content and P, K, Ca, Mg, Zn, Cu, Mn, and Fe concentrations by methods specified by Peters et al. \((2003)\). The carbon-to-nitrogen \((\text{C:N})\) ratio was calculated for all barns.

**Building Envelope.** Building measurements included building orientation and location \((\text{longitude and latitude})\); 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 \((\text{Damasceno, 2012})\).

**Compost Bed Temperatures.** Temperatures were collected once during each site visit at 9 evenly distributed locations within the barn. Temperature collection occurred at 10.2 and 20.3 cm deep using a thermocouple-based thermometer \((0.22\text{-m length, accuracy of } \pm 2.2^\circ C; \text{model 87; Fluke Inc., Everett, WA})\), and the CBP surface using an infrared thermometer \((\text{accuracy of } \pm 1^\circ C; \text{model 62; Fluke Inc.})\). Ambient temperature and relative humidity \((\text{RH})\) conditions were collected once at each site visit using a weather meter \((\text{Kestrel; accuracy of } \pm 1^\circ C; \text{model 4000; KestrelMeters.com, Sylvan Lake, MI})\).

### Statistical Analysis

**Descriptive Statistics.** The MEANS procedure of SAS \((\text{SAS 9.3; SAS Institute Inc., Cary, NC})\) was used to calculate means and standard deviations 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 ± standard deviation. The FREQ procedure of SAS was used to calculate producer comment and management practice frequencies.

**Herd Performance.** The MIXED procedure of SAS \((\text{SAS 9.3; SAS Institute Inc.})\) was used to develop models to describe DHIA data for herds using the CBP barn as a primary housing facility \((n = 8)\) and a special needs housing facility \((n = 7)\). Performance metrics, including milk production, SCC, culling, and reproductive performance, were compared for the 12 mo before \((\text{before})\), 1 to 12 mo after \((\text{transition})\), and 13 to 24 mo after \((\text{after})\) moving into the CBP barn. An individual model was developed for each performance metric, including the period relative to moving \((\text{before, transition, and after})\) as the fixed effect, where \(y = x \cdot \text{Date was treated as a repeated effect within each model, with the farm treated as the subject. All results are presented as the least squares means (±SE). The MIXED procedure of SAS was used to test the influence of the transition to the new facility \((\text{before or after})\) and season on BTSCC for producers using the CBP barn as a primary housing facility \((n = 9)\) or for special needs cows \((n = 3)\).**

**Temperature, Moisture, and Hygiene.** The GLM procedure of SAS \((\text{SAS 9.3; SAS Institute Inc.})\) was used to develop models to describe CBP moisture, CBP temperature at 20.3-cm depth, and mean herd hygiene, each of which were approximately normal. Four farms were excluded from the analysis because cows had ac-
cess to both a CBP barn and freestall barn, creating inaccurate stocking density estimations. An additional 6 farms were excluded from the moisture model because relative humidity data were not collected, leaving 32 farms for inclusion in models. Relevance and importance to the variable of interest influenced selection of explanatory variables chosen for model inclusion. All selected explanatory variables remained in the model, regardless of significance. Explanatory variables for CBP moisture included stirring depth, space per cow adjusted for pasture access (SQMP), and CBP drying rate. Space per cow was adjusted for pasture access and calculated using Equation 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.

\[
\text{SQMP} = \frac{\text{SQM}}{1 - \text{PAST}},
\]

where SQMP = space per cow (m²/cow) adjusted for pasture access, SQM (m²/cow) = total CBP area divided by the number of cows housed on the CBP, and PAST = percentage of time (expressed as a decimal) cows spent on pasture during the day at the time of the site visit. Drying rate is directly proportional to the air moisture concentration driving force, which was the difference between moisture in the air in equilibrium with the CBP surface (Csur; kg of H₂O/m³ of dry air) and ambient moisture concentration (Camb; kg of H₂O/m³ of dry air) (adapted from Equation 21.3a, page 655 of Bird et al., 1960). The air moisture concentration at the bed surface was saturated (100% RH) and was determined using the bed surface temperature. The ambient air moisture content was determined from a temperature and RH measure at 122 cm above the CBP. This linear relationship (Equation 2) was used in SAS (SAS 9.3; SAS Institute Inc.) 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.

\[
\text{DR} = K \times (\text{C}_{\text{sur}} - \text{C}_{\text{amb}}),
\]

where DR = drying rate (kg of H₂O/m² · s) and K = mean overall mass transfer coefficient (m/s), which was a function of air velocity (m/s) and ambient temperature (°C), and K was directly dependent on air velocity (inferred from Equation 21.2-25, page 647 of Bird et al., 1960), assuming 100% RH, C_{sur} = air moisture concentration at the CBP surface, and C_{amb} = ambient air moisture concentration.

Explanatory variables for CBP temperature included stirring frequency, stirring depth, ambient temperature, and space per cow. Explanatory variables describing mean herd hygiene included ambient temperature, CBP moisture, and 20.3-cm 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 2- and 3-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 CBP (n = 47). Producer-reported, or values verbally stated by the producer at the time of visit that may or may not be based on subjective reporting, 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 US Department of Agriculture National Agricultural Statistics Service (USDA/NASS, 2012) reported that daily milk production in Kentucky was 17.8 kg/d, which was lower than that reported by producers using the CBP barn. Norman et al. (2010) reported mean SCC in Kentucky of 313,000 cells/mL, which was 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 TMR (n = 36), although some practiced component feeding (n = 5) or a mixture of component feeding and a TMR (n = 1). In the summer, 26 producers operated a zero-grazing system, whereas 29 producers operated a zero-grazing system in the winter. Twenty-one farms pastured cows during the summer a mean of 40.3 ± 17.3% of the day; however, 18 producers pastured cows during the winter a mean of 37.4 ± 19.2% of the day. Eighteen producers offered some access to pasture year round, whereas 26 producers operated a zero-grazing system year round. Allowing pasture access reduces the amount of urine and manure voided while in the barn, reducing bedding requirements.

Producers chose to cull animals from the herd for a multitude of reasons, many of which are multifaceted. Producers indicated that their primary 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. Farms handled hoof problems through regular hoof trimming (n = 35), treating foot problems in the parlor (n = 29), and hoofbath use (n = 23). Most producers did not dock cow tails (n = 31), although some producers docked all tails (n = 6) and others docked some tails (n = 4). Most producers used AI (n = 27) rather than a bull (n = 23) to breed cows and 4 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.; http://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 controlled internal drug release (CIDR) insert (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, Washington, DC) 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. Three producers decided to use freestall designs for barn construction as an alternative plan if CBP did not suit their particular 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.

CBP 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 soy hull shavings. Klebsiella levels in the bedding and mastitis caused by Klebsiella bacteria were not investigated. However, 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. 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. 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. The initial amount of bedding added after cleanout would vary by the amount of old bedding material retained in the barn; however, this information was not recorded in this study. Winter weather required new shavings addition every 16.4 d (n = 40), ranging from every day to every 56 d. Summer weather required new shavings every 18.2 d (n = 39), ranging from every other day to every 45 d. Producers added a mean depth of 8.8 cm (n = 40) of shavings per bedding addition, ranging from 0.1 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% (Schulze, 1962; Gray et al., 1971a), although a range of 50 to 60% is preferred (Gray et al., 1971b; Suler and Finstein, 1977; NRAES, 1992). Producers can measure moisture by weighing material before and after drying to determine the need for bedding addition. However, no producers in the present study measured moisture, aside from visual assessment or squeezing the material.

Barn cleanout occurred 1.7 ± 0.8 times per year (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 contains some active microbial populations, as seen from bacterial populations sampled at the surface layer [R. A. Black, J. L. Taraba, G. B. Day, F. A. Damasceno, M. C. Newman (Department of Animal and Food Sciences, University of Kentucky, Lexington), K. A. Akers (Department of Animal and Food Sciences, University of Kentucky), C. L. Wood (Department of Statistics, University of Kentucky), K. J. McQuerry (Department of Statistics, University of Kentucky), and J. M. Bewley, unpublished data] and recent infiltration (Department of Statistics, University of Kentucky), and J. M. Bewley, unpublished data] and recent infiltration of air, 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. Berg et al. (2007a) reported a stocking density of 8.6 ± 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 2× per day in the summer, whereas 18 producers stirred the CBP 1× per day and 1 producer stirred the CBP 3× per day. In the winter, 33 producers stirred the CBP 2× per day, 13 producers stirred 1× per day, and 1 producer stirred 3× per day. 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 1× per day (n = 18), but 7 producers scraped 2× per day, 4 scraped once every other day, and 1 scraped 3× per day. 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 2× per day (n = 38) and 4 farms milked cows 3× per day. Milking procedures were posted in 5 parlors. Glove use during milking occurred on 31 farms. Forty-one producers used predip and all producers used postdip (n = 42). Predips used included iodine (n = 20), hydrogen peroxide (n = 5), sodium dichloroisocyanurate (n = 3), and chlorine dioxide (n = 1). Postdips used included iodine (n = 25), sodium chlorite (n = 3), chlorine dioxide (n = 3), and a combination of iodine and sodium chlorite (n = 1). Forty-one producers dried teats before attaching the milker and 34 producers used individual towels for each cow. Automatic takeoffs were used on 25 of the farms visited. Most farms had their milking systems analyzed annually (n = 39). Culturing of mastitic cows occurred on 18 farms, whereas 18 farms did not culture. Five farms cultured based on the case. Proper parlor procedures, especially the use of a postmilking 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 1 farm used dry cow antibiotic therapy (n = 41). All 4 quarters were treated by 29 producers and 17 producers used Orbesal (Pfizer Animal Health). Twenty-one producers used an Escherichia coli vaccine, including J-5 Strain (Pfizer Animal Health; n = 9), ENDOVAC-Bovi (Imvac Inc., Columbia, MO; n = 7), and J-VAC (Merial Ltd., Duluth, GA; n = 4). Twenty-nine farms managed dry cows on pasture or an exercise lot and 5 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 with freestall barns because of the reduced concrete requirement and the lack of stall hardware [Berg et al., 2007a; Janni et al., 2007; R. A. Black, J. L. Taraba, G. B. Day, F. A. Damasceno, M. C. Newman (Department of Animal and Food Sciences, University of Kentucky, Lexington), K. A. Akers (Department of Animal and Food Sciences, University of Kentucky), C. L. Wood (Department of Statistics, University of Kentucky), K. J. McQuerry (Department of Statistics, University of Kentucky), and J. M. Bewley, unpublished data], although 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 $85,400 ± 69,800 (n = 37), ranging from $10,900 to $300,000. 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 $103,700 ± 74,200 (n = 24), ranging from $30,000 to $300,000, 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), ranging from $10,00 to $155,000, on total 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. Additionally, barns built within the state of Kentucky do not require a concrete base. Producers building barns requiring a concrete base would require a greater capital investment. Barn costs per cow (assuming 9.3 m² per cow) were $1,051 ± 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 $1,013 ± 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-based freestall (MF) barn, 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 SF barn. However, although 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 soy hulls (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 or using GS added more shavings to the CBP per cow per day (0.07 ± 0.03 and 0.07 ± 0.06 m³/cow per day, respectively) than producers using KDS (0.05 ± 0.04 m³/cow per day). A MIX cost $0.70 ± 0.49 per cow per day, KDS cost $0.35 ± 0.37 per cow per day, and GS cost $0.26 ± 0.32 per cow per day. 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. Bedding costs vary from region to region.

An SF barn requires 18.2 kg of sand per stall per day (Gooch et al., 2003) and sand bedding costs $0.0099 per kilogram (Buli et al., 2010). Assuming cows were stocked to allow 1 stall for every cow, SF bedding cost $0.18 per cow per day. Sand freestalls are deep-bedded stalls, which 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). Producers typically add new bedding 3.9 times per week (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 m³ of sawdust bedding. Producers bedding freestall barns likely use a variety of different sawdust materials similar to the CBP barn costing $6.55/m³. Therefore, MF bedding cost $0.13 per cow per day. 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 that they liked, aspects they would change, recommendations to other farmers, and lessons learned throughout their time managing the CBP barn based on their experiences and own judgments. Of the 42 producers, 41 responded that they were satisfied with their CBP barn and 1 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 (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 included (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, 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 around the perimeter of the barn (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 secure an adequate bedding supply. Other recommendations included stirring the CBP 2× per day (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 1 depicts CBP nutrient compositions. The C:N 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 ratio 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 with 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 ratio 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 ratio in the compost at the time of application as fertilizer and nitrogen availability to the soil, stating that a C:N ratio 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, including wood chips, flax straw, wheat straw, oat hulls, straw dust, and soybean straw, do have the ability to produce C:N ratios suitable for composting (Shane et al., 2010), although 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 1) contained 0.40 ± 0.15% P, 1.30 ± 0.52% K, 2.01 ± 3.15% Ca, 0.45 ± 0.21% Mg, 110.37 ± 45.91 mg of Zn/kg, 27.76 ± 15.53 mg of Cu/kg, 222.41 ± 135.00 mg of Mn/kg, and 2,779.73 ± 2,339.44 mg of Fe/kg. Most manure contains sufficient nutrient concentrations to satisfy crop needs; however, testing soil to determine nutrient contents may be beneficial for not over- or underapplying nutrients.

Temperature. The mean collection-day 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

<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>C, %</td>
<td>41.8</td>
<td>5.1</td>
<td>20.9</td>
<td>47.1</td>
</tr>
<tr>
<td>N, %</td>
<td>1.7</td>
<td>0.5</td>
<td>1.0</td>
<td>2.9</td>
</tr>
<tr>
<td>C:N¹</td>
<td>26.7</td>
<td>7.8</td>
<td>11.3</td>
<td>43.2</td>
</tr>
<tr>
<td>P, %</td>
<td>0.4</td>
<td>0.2</td>
<td>0.2</td>
<td>0.9</td>
</tr>
<tr>
<td>K, %</td>
<td>1.3</td>
<td>0.5</td>
<td>0.4</td>
<td>3.0</td>
</tr>
<tr>
<td>Ca, %</td>
<td>2.0</td>
<td>3.2</td>
<td>0.6</td>
<td>22.3</td>
</tr>
<tr>
<td>Mg, %</td>
<td>0.5</td>
<td>0.2</td>
<td>0.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Zn, mg/kg</td>
<td>110.4</td>
<td>45.9</td>
<td>36.5</td>
<td>217.9</td>
</tr>
<tr>
<td>Cu, mg/kg</td>
<td>27.8</td>
<td>15.5</td>
<td>7.8</td>
<td>61.9</td>
</tr>
<tr>
<td>Mn, mg/kg</td>
<td>222.4</td>
<td>135.0</td>
<td>110.8</td>
<td>818.9</td>
</tr>
<tr>
<td>Fe, mg/kg</td>
<td>2,779.7</td>
<td>2,539.4</td>
<td>471.4</td>
<td>9,077.7</td>
</tr>
</tbody>
</table>

¹Carbon-to-nitrogen ratio was calculated as C content (%) divided by N content (%).
temperature of 42.5°C across 12 barns and 4 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 effect of a low temperature on the overall mean. 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), 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 decrease 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 explanatory variables and estimated coefficients for the model of 20.3-cm CBP depth temperature are expressed in Table 2. Stirring frequency, ambient temperature, and the quadratic and cubic transformation of stirring depth affected 20.3-cm depth CBP temperature (Table 2; \( P \leq 0.05 \)). Compost bedded pack temperatures increased as ambient temperatures increased (Table 2; \( P < 0.05 \)). 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 cooler 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; \( P < 0.01 \)) from a mean of 30.0 ± 2.7°C with 1×/d stirring to 40.0 ± 1.9°C with 2×/d stirring. 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 2 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. Klingendfu, Harvest Home Dairy, Crestwood, KY; personal communication), but improves composting efficiency. Increasing stirring depth also increased CBP temperature (Table 2; \( P = 0.04 \)). 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; Suler and Finstein, 1977; Stentiford, 1996). 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 with 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 explanatory variables and estimated coefficients for the model of CBP moisture are expressed in Table 3. Drying rate, calculated us-
ing Equation 2, significantly affected CBP moisture (Table 3; \( P < 0.05 \)). Increasing drying rate reduced CBP moisture \( (P < 0.01) \). However, it should be noted that drying rate measurements occurred only once per farm and not over a continued period to represent different ambient environments, which is a limitation of this measurement. A more thorough analysis over time would represent a more complete range of environments and scenarios. Nevertheless, 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 locomotion score was 1.5 ± 0.9 \( (n = 1,719) \). Only cows housed on the CBP as the primary means of housing were included in locomotion scoring. 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 a 1, 57.9% scored a 2, 23.2% scored a 3, and 6.6% scored a 4. Almost one-third of the cows scored for hygiene during the current study, 12.3% scored a 1, 56.1% as 2, 18.6% as 3, 5.8% as a 4, and 0.3% scoring a 5 \( (n = 5,626) \), 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 with freestall barns (Phillips and Schofield, 1994; Vaarst et al., 1998; Somers et al., 2003). Less time is spent standing on concrete flooring, which can reduce hoof disorders (Sogstad et al., 2005). Eckelkamp et al. (2014) reported that cows transitioning from an outdated freestall barn to a CBP barn spent 4 h/d more lying than in the freestall system \( (13.1 \text{ vs. } 9.1 \text{ h/d, respectively}) \). Further, lame cows (locomotion score ≥3, using the scoring system of Sprecher et al. (1997)) spent 5 h/d more lying on the CBP compared with the freestall system \( (13.1 \text{ vs. } 8.0 \text{ h/d, respectively; } P < 0.05) \). 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 \( (10.1 \text{ vs. } 13.1 \text{ h/d, respectively; } P < 0.05) \).

**Hygiene.** Proper cow hygiene management can reduce mastitis risk (Neave et al., 1969; Schreiner and Ruegg, 2003; Reneau et al., 2005). 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 cow hygiene score was 2.2 ± 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. Almost one-third of the cows scored were considered dirty \( (\text{hygiene score ≥3}) \). Barberg et al. (2007b) observed a mean herd hygiene score of 2.66 for the 12 CBP barns visited. Shane et al. (2010) observed a mean herd hygiene score of 3.10 for 6 CBP barns.

### Table 3. Estimated coefficients for model of compost bedded pack (CBP) moisture

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>( P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>74.7190</td>
<td>4.27</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Stirring depth, cm</td>
<td>−0.2494</td>
<td>0.16</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>0.16</td>
</tr>
<tr>
<td>Drying rate, (^2) kg of H(_2)O/m(^2)-s</td>
<td>−51.5479</td>
<td>8.43</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

\(^1\)Space per cow calculated as total CBP area divided by total number of cows housed on CBP. Space per cow was adjusted by dividing by 1 – percentage of time (expressed as a decimal) spent on pasture per day.

\(^2\)Drying rate was calculated as the mean overall transfer coefficient (K; m/s) times the difference between air moisture concentration at the compost bedded surface (kg of H\(_2\)O/m\(^3\) of dry air) and the ambient air moisture concentration (kg of H\(_2\)O/m\(^3\) of dry air).

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*Source: Journal of Dairy Science Vol. 96 No. 12, 2013*
A study comparing CBP barns, cross-ventilated barns, and naturally ventilated barns noted that cows housed in CBP barns had increased hygiene scores (3.18) compared with the cross-ventilated (2.83) and naturally ventilated (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 explanatory variables and estimated coefficients for the model of mean herd hygiene are expressed in Table 4. Ambient temperature, 20.3-cm depth CBP temperature, and the interaction between moisture and ambient temperature significantly affected mean herd hygiene (Table 4; \( P < 0.05 \)). Increasing 20.3-cm depth CBP temperature reduced mean herd hygiene scores (Table 4; \( P < 0.01 \)). 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 ± 11.0°C) would support minimal material degradation.

The interaction between moisture and ambient temperature significantly affected mean herd hygiene (\( P < 0.01 \)). When moisture was low (35%; Jeris and Regan, 1973; Sulier and Finstein, 1977; Stentiford, 1996) and ambient temperature was high, mean herd hygiene scores were reduced. However, when moisture was high (70%; Jeris and Regan, 1973; Sulier and Finstein, 1977; Stentiford, 1996) and ambient temperature was high or low, mean herd 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 with the summer (3.33 vs. 3.21, respectively), although 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 was scored as a 3 or 4 compared with cows that 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 that 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 year before moving into the CBP barn to the year after (323,700 ± 7,300 vs. 252,900 ± 7,100 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 with fall, spring, and winter (323,900 ± 10,500 vs. 288,300 ± 10,100, 272,800 ± 10,100, and 265,200 ± 10,100 cells/mL, respectively; \( P < 0.05 \)). No seasonal differences relative to compost barn construction were observed. Barkema et al. (1998) 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,

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>( P )-value</th>
</tr>
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<td>Ambient temperature, °C</td>
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<tr>
<td>20.3-cm-depth pack temperature, °C</td>
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<td>0.01</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Pack moisture, %</td>
<td>−0.0188</td>
<td>0.01</td>
<td>0.32</td>
</tr>
<tr>
<td>Ambient temperature × pack moisture</td>
<td>0.0017</td>
<td>0.00</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

1Hygiene was scored on a scale of 1 to 4, where 1 is clean and 4 is filthy (Cook and Reinemann, 2007).
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 (292,100 ± 11,000 vs. 299,600 ± 11,300 cells/mL, respectively; P > 0.05). Summer-season SCC were higher compared with spring, fall, and winter (359,400 ± 14,800 vs. 302,500 ± 15,700, 279,200 ± 14,800, and 242,300 ± 17,400 cells/mL, respectively; P < 0.05); however, the winter season produced a lower SCC compared with spring (P < 0.05). Most cows in these herds were housed in freestall barns and the BTSCC is more affected 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 5 includes the mean herd performance metrics for the year before (12 mo before moving into the CBP barn), transition year (1 to 12 mo after moving into the CBP barn), and second year (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 year 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 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 the year before to the second year 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, including predip, postdip, gloves, and individual towels, to ensure hygienic conditions during milking. Improvement in reproductive parameters from the year before to the second year after barn occupation occurred, including calving interval (14.3 ± 0.1 vs. 13.7 ± 0.1 mo, respectively; P < 0.05), days to first service (104.1 ± 3.0 vs. 85.3 ± 3.0 d, respectively; P < 0.05), and days open (173.0 ± 3.5 vs. 153.4 ± 3.4 d, respectively; P < 0.05). An increase in the percentage of heats observed occurred from the year before to the year after barn occupation (42.0 ± 2.6 vs. 48.7 ± 2.5%, respectively; P < 0.05). However, observed heats decreased from the first year of occupation to the second (48.7 ± 2.5 vs. 39.5 ± 2.5%, respectively; P < 0.05). An increase in percentage 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 6 includes the mean herd performance metrics for the year before, transition year, and second year 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, days 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 effect 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 percentage of successful breedings (34.3 ± 1.7 vs. 41.9 ± 1.7%; P < 0.05) and a decrease in the percentage of heats observed (53.4 ± 2.1 vs. 46.0 ± 2.1%; P < 0.05) from the year before to the second year 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, frequency, and space per cow increased CBP temperature, whereas increased stirring depth, space per cow and drying rate decreased CBP moisture. Implementing these management practices to reduce CBP moisture and increase CBP temperature improved mean herd hygiene score. In cold weather, producers should provide more space per cow or increase evaporation while cows are in the parlor to reduce moisture within the pack. Housing cows on the CBP resulted in relatively sound cows, which was consistent with previous findings. Housing cows on the...
CBP as the primary means of housing resulted in an increase in milk production and a reduction in SCC, calving interval, and days open when transitioning to a new CBP barn, supporting benefits previously reported for the CBP barn system. However, producers practiced meticulous parlor management to ensure hygienic conditions during milking, indicating that hygiene and parlor management are a high priority when operating a CBP barn. Barn investment was reduced compared with the freestall housing system; however, variable cost associated with bedding was increased. Kiln-dried shavings resulted in the least amount of bedding added per cow per day compared with green shavings and a mixture of shavings. However, bedding cost in different areas varies, making the best option dependent on cost per cubic meter. Upon removal of CBP material from the barn, additional composting would be advantageous for a more sanitized and nutritive product to be used on fields as fertilizer. The volatility of CBP performance requires meticulous management by the producer to ensure that the CBP does not fail, resulting in herd health concerns. This includes adequate aeration, bedding addition, space per cow, and ventilation. Producer observations and analysis of additional factors affecting compost performance will benefit existing and future adopters of the CBP barn system.

**ACKNOWLEDGMENTS**

We 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 (Lexington) consultants who assisted with the project and University.

### Table 5. Least squares means of the changes in production and reproductive parameters for 8 farms\(^1\) enrolled in DHIA before and after moving in a compost bedded pack (CBP) barn

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time period (^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
</tr>
<tr>
<td>Daily milk production, kg</td>
<td>29.3 ± 0.3(^a)</td>
</tr>
<tr>
<td>Rolling herd average milk production, kg</td>
<td>8.937 ± 79(^a)</td>
</tr>
<tr>
<td>Mature-equivalent 305-d milk production, kg</td>
<td>10,223 ± 77(^a)</td>
</tr>
<tr>
<td>SCC, cells/mL</td>
<td>411,230 ± 20,209(^a)</td>
</tr>
<tr>
<td>Actual calving interval, mo</td>
<td>14.3 ± 0.1(^a)</td>
</tr>
<tr>
<td>Days to first service, d</td>
<td>104.1 ± 3.0(^a)</td>
</tr>
<tr>
<td>Days open, d</td>
<td>173.0 ± 3.5(^a)</td>
</tr>
<tr>
<td>Percentage successful, %</td>
<td>38.4 ± 1.2</td>
</tr>
<tr>
<td>Percentage of heats observed, %</td>
<td>42.0 ± 2.6(^ab)</td>
</tr>
<tr>
<td>Pregnancy rate, %</td>
<td>15.4 ± 1.9</td>
</tr>
</tbody>
</table>

\(^a,b\) Different superscripts within a row denote a significant difference \((P < 0.05)\).

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

\(^2\) Time period includes the 12 mo before moving into the CBP barn; transition represents the 12 mo after moving into the CBP barn; after represents the 13 to 24 mo after moving into the CBP barn.

### Table 6. Least squares means in the changes in production and reproductive parameters for 7 farms\(^1\) enrolled in DHIA before and after moving in a compost bedded pack (CBP) barn

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time period (^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
</tr>
<tr>
<td>Daily milk production, kg</td>
<td>28.1 ± 0.5</td>
</tr>
<tr>
<td>Rolling herd average milk production, kg</td>
<td>8.965 ± 160</td>
</tr>
<tr>
<td>Mature-equivalent 305-d milk production, kg</td>
<td>9.808 ± 150</td>
</tr>
<tr>
<td>SCC, cells/mL</td>
<td>296,780 ± 13,576</td>
</tr>
<tr>
<td>Actual calving interval, mo</td>
<td>14.2 ± 0.1</td>
</tr>
<tr>
<td>Days to first service, d</td>
<td>91.7 ± 1.6</td>
</tr>
<tr>
<td>Days open, d</td>
<td>174.8 ± 3.2(^a)</td>
</tr>
<tr>
<td>Percentage successful, %</td>
<td>34.3 ± 1.7(^a)</td>
</tr>
<tr>
<td>Percentage of heats observed, %</td>
<td>53.4 ± 2.1(^a)</td>
</tr>
<tr>
<td>Pregnancy rate, %</td>
<td>12.5 ± 1.3</td>
</tr>
</tbody>
</table>

\(^a,b\) Different superscripts within a row denote a significant difference \((P < 0.05)\).

\(^1\) All farms included used the CBP barn as a special needs housing facility.

\(^2\) Before represents the 12 mo before moving into the compost bedded pack barn; transition represents the 12 mo after moving into the CBP barn; after represents the 13 to 24 mo after moving into the CBP barn.
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REFERENCES


