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COMPOST BEDDED PACK DAIRY HOUSING: ANIMAL PERFORMANCE AND
WELL-BEING AND ECONOMIC VIABILITY IN A PASTURE-BASED SYSTEM

________________________________________
DISSERTATION
________________________________________

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the College of Agriculture, Food and Environment at the University of Kentucky

By
Betty Kawonga
Lexington, Kentucky

Director: Dr. M. Morgan, Professor of Animal Science
Lexington, Kentucky
2018

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ABSTRACT OF DISSERTATION

COMPOST BEDDED PACK DAIRY HOUSING: ANIMAL PERFORMANCE AND WELL-BEING AND ECONOMIC VIABILITY IN A PASTURE-BASED SYSTEM

Improving housing for dairy cattle is of interest because hoof and udder health, which are associated with the housing environment, are important economic and welfare issues. The objectives were: 1) to assess the influence of housing—conventional cubicle (CCD) vs compost bedded pack (CBP)—and management (grazing vs semi-grazing) on the performance and welfare in dairy cows 2) describe the performance of the CBP under a grazing or semi-grazing system, and 3) to assess viability of CBP housing in a pasture-based system. This study mixes three research approaches, an analysis of existing and secondary data; an experiment, and a case-study. If taken out of context and used in isolation, this mix of methods would lead to ambiguity and confusion. But in the context of the Malawi dairy industry, it is by mixing these methods that we can best inform farmer’s decisions about the type of structures that best serve them individually and the Malawian dairy industry as a whole. Cows were evaluated weekly for udder, hock, and hoof health, under a grazing (cows kept at pasture for 33 to 42% of the day) and semi-grazing system (cows kept at pasture for 16.67% of the day). No difference was observed between grazing and semi-grazing system regarding milk yield, hoof, hock, and udder health. Sub-clinical high SCC prevalence and SCC were 22% and 48% lower in the CBP barn than in the CCD barn. Cows in the CBP produced 1.2 kg per cow/day more milk than cows in CCD. No difference in CBP performance was observed under a grazing or semi-grazing system. Partial budget analysis showed that CBP was viable with net returns of $881. The benefits of the CBP over CCD are $ 1425 per year, but it would take an investment of $5368. The farmer would be expected to pay back the investment in 3.77 years.

Key words: Housing, compost dairy barn, viability

. Betty Kawonga

. December, 2018
COMPOST BEDDED PACK DAIRY HOUSING: ANIMAL PERFORMANCE AND WELL-BEING AND ECONOMIC VIABILITY IN A PASTURE-BASED SYSTEM

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Abbreviations

C:N = Carbon to Nitrogen Ratio
CBP = Compost bedded pack
CCD = Conventional cubicle dairy
COMESA = Common Market for Eastern and Southern Africa
d = Day
DIM = Days in milk
DM = dry matter
kg = Kilogram
LSM = Least Square Means
MBG = Milk Bulking Group
mL = Mililiter
Mo = Month
NSO = National Statistical Office
RH = Relative humidity
SCC = Somatic cell count
SD = Standard Deviation
SE = Standard error
THI = Temperature humidity Index
wk = Week
y = Year
Chapter One: Review of Literature

Introduction

To promote the dairy industry, the Malawian government established milk bulking groups (milk bulking and selling points) to provide milk testing and bulking services to dairy producers located within a 15 km radius from these milk bulking groups. Other improvements to promote hygiene and ensure consumer safety included the establishment of standards for milk and milk products, regular inspections of farms and milk processing plants, and milk and milk product sampling and testing (Chagunda et al., 2012). Also, the government established the conventional cubicle dairy (CCD) housing for zero-grazing system (“systems in which cows are kept indoors without outdoor access”) to promote the well-being, health, and production of dairy cows.

The ability of any housing system to provide comfort for the cow is an important aspect for dairy cows. The CCD housing and zero-grazing system have been typically associated with low lying time (Banda, 2014) and moderate prevalence of lameness (Tebug, 2012). In most cases, little or no bedding is applied in the cubicles exposing cows to concrete or brick flooring (Gibbons et al., 2010a, Kawonga et al., 2012). Exposure of cows to hard lying surfaces can result in lameness. Also, cows in these cubicles stand for most of the day (13 hours standing vs 9 hours lying down) (Banda et al., 2014), which results in a high accumulation of urine and feces, which can be controlled by adequate stall grooming.

Compost bedded pack (CBP) dairy barns, a loose housing system, is an attempt to alleviate some of the challenges associated with confining cows on concrete. This done in part by offering animals a large, open resting area and a softer lying surface to increase cow comfort (Barberg et al., 2007a, Lobeck et al., 2011, Black et al., 2013). Researchers speculate that
comfortable, well-nourished cows can handle stress better than cows in poor health (Bewley et al., 2013). However, to optimize the economics of dairy cattle housing, excellent housing and high-quality housing environments must be achieved at a low cost. Several researchers have evaluated the viability of investing in the CBP barns. The net returns vary for the type of farm, initial cost of the CBP barn, and cost of bedding materials. For example, converting a freestall with an attached feed alley into a CBP barn reduced the initial barn cost, resulting in greater net returns (Black, 2013). Also, allowing cows access to pasture reduced bedding costs (Black, 2013) because less urine and feces were deposited on the bedded pack. However, combining the CBP barn with other management systems such as grazing or semi-grazing may have adverse effects on the performance of the pack and subsequent viability of the CBP housing. Combining CBP with grazing or semi-grazing systems may result in low pack moisture content because less urine and feces will be deposited on the bedded pack. The composting process is effective at moisture levels of 40% to 60% (NRAES, 1992). If moisture falls below 15% (wet basis), microbial biological activities cease because of high matrix suction, which limits water availability to microorganisms (NRAES, 1992). Also, if the composting bed contains less than 40% moisture, the risk of high-temperature damage is high (NRAES, 1992). Therefore, understanding the effect of grazing vs semi-grazing systems on compost bed performance can help producers incorporate flexibility in the day-to-day management of the CBP barn.

**Dairy Cattle Housing and Management System: Effects on Performance and Well-being in Dairy Cows**

**Claw Health**

Lameness is a devastating disease that afflicts the dairy industry, and it causes substantial economic losses worldwide (Cook, 2003, Viguier et al., 2009). Whay et al. (2003) found that lameness affected up to 50% of cows on some farms. Dippel et al. (2009) found that, in
Germany, lameness in freestalls ranged from 0% to 81%. Lameness has been identified even in small-scale zero-grazing herds in Africa (Tebug, 2012). Haskell et al. (2006a) assessed the effect of management and type of housing on the prevalence of lameness in dairy cows. Lameness was greater on zero-grazing farms (39 ± 0.02%) than on grazing farms (15 ± 0.01%) (Haskell et al., 2006a). However, providing cows in a zero-grazing system with access to pasture can minimize lameness in dairy cows (Hernandez-Mendo, 2007).

Lameness appears to be lower in loose housing systems such as straw yards compared with cubicle housing or freestalls (Haskell et al., 2006a). Lameness in freestalls was associated with less stall usage, stall maintenance, and cow hygiene (Cook et al., 2004b, Haskell et al., 2006a, Lombard et al., 2010). Wet, manure contaminated stalls, in addition to the lack of surface cushioning, have all been associated with an increase in lameness (Cook et al., 2004a, Cook and Nordlund, 2009). The lower lameness prevalence in loose housing systems, such as compost bedded pack barns or straw yards, than in freestalls could be because cows spend less time standing on concrete and there are no partitions allowing cows to stand up and to lay down more naturally (Janni et al., 2007, Lobeck et al., 2011).

Nutritional management factors, such as feeding cows diets high in fermentable carbohydrates, can contribute to laminitis (pododermatitis aseptic diffusa-- an inflammation of the dermal layers inside the foot) (NRC, 2001). Also, abrupt changes in diet for lactating cows from a high forage diet to a high energy diet can lead to a buildup of lactate because lactate converting bacteria respond slowly to a change in diet. A buildup of lactic acid and endotoxins as rumen microflora die, can result in clinical laminitis due to the disruptive nature of lactic acid and endotoxins on the structure of the hoof during development (NRC, 2001).

Inadequacies in dairy cattle housing can predispose cows to mechanical damage, these include hard lying surfaces such as concrete, lack of or little use of bedding in the stalls, lack of or excessive exercise on hard lying surfaces, and exposure to slurry. However, when given access
to clean and dry stalls, cattle will spend more time lying in their stalls and less time standing and walking in the alleyways, resulting in cleaner and drier feet (Cook et al., 2004b).

**Hock Lesions**

Hock lesions are used to assess the welfare of dairy animals (Whay et al., 2003). Hock lesions are associated with the condition of lying surfaces (Cook, 2003, Cook, 2002). This animal-based measure reflects the health and behavior of animals in relation to the husbandry systems and environments in which they live (Whay et al., 2003, Telezhenko and Bergsten, 2005). Haskell et al. (2006a) found fewer hock and knee injuries on straw yard farms than freestall farms. The frequency of knee swellings was greater on zero-grazing farms (0.31 ± 0.02) than on grazing farms (0.15 ± 0.01) (Haskell et al., 2006a), possibly due to the effect of concrete or continual exposure of feet to slurry (Cook et al., 2004b).

**Lying Time and Milk Production**

One advantage of keeping cows indoors is that cows in confinement are motivated to lie down for 12 to 13 h/d (Munksgaard et al., 2005), when on softer surfaces (Rushen et al., 2007). However, when on hard surfaces like concrete, cattle are less motivated to lie down (Cook et al., 2004b, Rushen et al., 2007). For example, Banda (2014) found that cows housed in a cubicle housing system with concrete flooring spend 15 h standing versus 9 h lying regardless of the hygiene of the pen, which leads to the speculation that the type of lying surface such as concrete might be a key determinant for pen usage.

With concrete, cows are exposed to hard surfaces for most part of the day, which can affect lying time (Tucker and Weary, 2004, Dippel et al., 2009) and milk yield (Ruud et al., 2010). However, providing cows with a softer lying surface may improve milk yield (Ruud et al., 2010), lying times, and stall usage (Tucker and Weary, 2004). Lying time increases with the use of deep bedding Ito et al. (2014a), because cows favor soft surfaces more than hard surfaces (Tucker et al., 2003, Telezhenko et al., 2007, Ito et al., 2014b). Also, cows on soft bedding lie
down and stand up twice as much as cows on concrete because the softer beds provide a better footing than does concrete (Haley et al. (2001). If lying surfaces are not comfortable and cows are deprived of sufficient lying time, they can be subject to a decrease in the circulating levels of growth hormone, a component that is important in milk synthesis (Munksgaard and Løvendahl, 1993). Also, blood flow to the udder is greater when cows lie down more, resulting in greater milk production. For example, 5 liters of blood flow through the teat per minute when cows are lying down compared with 3 liters of blood per minutes when standing.

**Udder Health**

Mastitis, an inflammation of the udder, can greatly reduce milk production. Tebug (2012) suggested a variety of probable risk factors for mastitis in dairy cows, including barn hygiene, management systems, season, milking hygiene practices, and floor types. The odds of mastitis occurring were greater during the rainy season (odds ratio = 5.07; 95% CI = 1.84 – 14.03) and in cows housed in dirty barns (odds ratio = 3.15, \(P < 0.05\)) (Tebug (2012). Cows housed in clean barns exhibited lower mastitis prevalence compared with cows housed in dirty sheds (41.3 vs 70.8%, respectively, \(P = 0.001\)) (Tebug, 2012).

Mastitis prevalence was greater during the rainy season compared with the dry season (71.3% vs 29.4%, \(P = 0.000\), respectively) (Tebug, 2012). Mastitis prevalence was greater on concrete than other floors such as brick flooring (83.3 vs 50%, respectively).

Field experience with dairy cattle housing in Malawi has shown that, on brick or clay floors, permanent pits easily develop over time, under the pressure of cow claws, making the brick and clay surfaces dirtier due to difficulties with cleaning especially during the rainy season than concrete floors (Kawonga et al., 2012, Tebug, 2012). There are differences between the two flooring types—namely ease of cleaning and overall stall hygiene—and these differences might be important to the occurrence of clinical mastitis and cow hygiene.
Risk factors for mastitis do not show causal relationships but indicate more about the state of the housing environment and how it predisposes the individual animal to disease pathogens (Tebug, 2012). The primary cause of mastitis is the microorganisms that invade the udder, multiply, and produce toxins that are detrimental to the mammary gland. It follows therefore, that the hygiene of the cow and that of the barn could be more important in determining whether the pathogens invade the teat end or not. Less hygienic conditions are a risk factor for mastitis and keeping the housing environment clean is important in managing mastitis caused by environmental pathogens.

Bedding material provides comfort through thermal effusion and surface softness, and it helps keep cows clean and healthy (Chaplin et al., 2000). However, bedding material is also home to the environmental pathogens that cause mastitis (Zdanowicz et al., 2004). The bacteria types and counts found on the teat ends are associated with the bacteria types and counts found in bedding materials (Hogan et al., 1989b, Eckes et al., 2001). Zdanowicz et al., (2004) found greater bacteria counts in organic bedding materials than in inorganic bedding materials. It follows accordingly, then, that best-management practices in housing are necessary for reducing unwanted bacteria found in the bedding. Because bacteria that are present on the teat end can be a source of new intramammary infection (IMI) and can end up in the bulk tank, the success of organic bedding use in animal housing systems hinges on excellent pre-milking cow prep and on the day-to-day management of the housing systems. Excellent pre-milking cow prep incorporates the following practices: use of 1 cloth per cow, fore-stripping, pre-dipping, and post-dipping.

The goal of any housing system is to provide sufficient and comfortable lying surfaces for dairy cattle. Thus, consideration in choice of housing design should include the flooring. Ruud et al. (2010) evaluated the effect of lying surfaces (concrete vs soft mats) on teat lesions and incidence of clinical mastitis. Ruud et al. (2010) found that the hazard ratio (HR) of teat lesions
on soft mats [HR = 0.33 (0.24–0.44)] was lower than on concrete [HR =0.47 (0.33–0.67)]. Ruud et al. (2010) also found fewer incidences of clinical mastitis and teat lesions in freestalls with soft bases compared to those with concrete, demonstrating that the risk of painful teat lesions and risk for clinical mastitis is lower on soft lying surfaces than on concrete (Telezhenko and Bergsten, 2005). Therefore, when greater milk yield or a reduction in the incidence of clinical mastitis and teat lesions is the objective, Ruud et al. (2010) recommended the use of soft floorings in free stalls for dairy cows.

**Compost Bedded Pack Dairy Housing System**

Compost bedded pack (CBP) dairy barns, which are loose housing (Janni et al., 2007), are designed to provide a large open area containing a bedded pack on which animals can rest (Janni et al., 2007, Barberg et al., 2007a). The CBP barn can be a primary housing structure for lactating cows, for multiple groups of cows, and for special needs cows (Janni et al., 2007, Black et al., 2013). The bedded pack is a bed of organic matter that is actively going through aerobic decomposition in the tilled layer, while an anaerobic layer forms under the tilled layer and continues the decomposition processes.

The bedded pack is tilled twice per day at a depth of 25 cm (Janni et al., 2007) in an attempt to keep the surface clean and dry (Janni et al., 2007, Black, 2013, Black et al., 2013); the clean, dry surface is necessary to reduce teat-end exposure and to prevent dirty cows. However, frequent stirring increases air flow into the tilled layers of the bed and exposes the bed to ambient air, increasing moisture evaporation.

To build a composting surface atop the bedded pack or a bare surface, bedding materials such as wood sawdust or wood shavings are spread over the bedded area. A bedding depth of 30.48 to 60.96 cm is needed to start the bedded pack, and the initial bedding amount depends on the size of the barn (Galama, 2009). Often, farmers add new bedding every 1 to 8 weeks (Black et al.,
2014); however, the frequency of adding bedding depends on the weather and on the condition of the pack surface tilled layer. For example, lower temperature of winter in some areas of North America such as in Kentucky can reduce the ability of the air holding capacity of water (lower concentration in g/m3), resulting in reduced drying rate. Microbial activities tend to slow down in cold weather, which can lead to low heat in the pack.

Sawdust is the bedding of choice in CBP barns. Sawdust improves microbial activity because of the high surface to volume ratio. Also, the greater lignin content helps to improve the structure of the compost bed. Further, the high lignin content resists degradation, allowing for longer composting time, which can reduce bedding requirements.

**Compost Bedded Pack Dairy Barn Design Features**

The design of compost bedded pack barns accomplishes 3 environmental goals: 1) simplify nutrient management, 2) reduce fly populations, and 3) improve air quality. For nutrient management, manure in the pack barns can be handled as solid waste, which allows more flexibility in land applications (NRAES, 1992). Reduced odor, dust, and emissions improve the air quality.

The suggested layout of a compost bedded pack barn, as designed by the University of Wisconsin (Figure 2), has a covered feeding area easily accessible by a concrete alleyway, which is a drive-by or drive-through feed alley with pens on both sides. Additionally, a concrete retaining wall surrounds the composted pack and separates it from the feed alley, and a walkway allows for easy access to and from the composted pack resting area (Janni et al., 2007, Taraba et al., 2013).

The space allotted to cows in the barns depends on the breed; for example, in the USA, Jersey cows get 7.4m²/cow of lying space, whereas Holstein cows get 10 m²/cow. However, in the European and Israeli barns, recommendations are for much more space. Maintaining the recommended space per cow is critical because overstocking will lead to more manure per
square m, and the resulting increased urine and manure causes a rise in pack moisture and can compromise hygiene and udder health. Space per cow is based on 2 factors that have to be balanced by the producer: 1) water production in the urine and feces of the cow in the resting area based on breed and milk production, and 2) the maintenance of the compost moisture level that will occur by either adding dry bedding or increasing the area per cow to allow more compost moisture to evaporate per cow (Bewley et al., 2013).

A concrete wall 0.6 to 1.2 m high surrounds the bedded pack and separates it from the feed alley. This separation wall is important to avoid excess moisture on the bedded pack, and it usually has barriers to prevent the cattle from incurring injuries when the pack depth changes (Endres and Barberg, 2007). The open space above the side wall allows for good aeration. The bedded pack can have a concrete or a clay base (Janni et al., 2007), though the use of a clay base can reduce the initial building cost. If the compost moisture does not exceed the maximum recommended level of 65%, the water holding capacity of compost is not reached where there is water drainage. Multiple walkways (3.05 to 3.65 m wide) run alongside the barn, providing cows and equipment access to the bedded pack and feed alley.

The walkways also improve the distribution of cattle on the bedded pack, and they minimize wet bedding at the entrances (Bewley and Taraba, 2012, Black, 2013). Wet bedding (> 60% wb) is problematic because it can lead to dirty cows, to high SCC, and to high clinical mastitis incidences (Black et al., 2014).

Feed alleys are 4.2 to 4.8 m wide, allowing cows easy access to feed and water and minimizing the risk of injury (Gay, 2009). Waterers are constructed to allow for 10 to 15 cows per waterer opening, and they can be placed adjacent to the feed platform or to the resting space, making them a short walking distance from the bedded pack (Endres and Barberg, 2007).
Composting Process

The decomposition of organic matter is a natural process (NRAES, 1992). However, regulating and optimizing the conditions under which matter decomposes will ensure a faster process. For efficient composting, microorganisms need suitable environmental conditions such as moisture, temperature, pH, oxygen, and carbon-to-nitrogen ratio. Once these conditions are met, the resident microorganisms—primarily bacteria—colonize the material and begin the composting process, breaking down the organic matter into a mulch-like product; the initiation of this process can be expedient since bacteria are already present in the composting materials (bedding and manure).

Composting allows for the conversion of organic matter into a stable compost that, if properly managed, is odorless and pathogen-free (Willson and Hummel, 1975, NRAES, 1992, Eghball et al., 1997). But, the compost present in the bed still is not the typical fully mature compost, since the aerobic layer is in the active composting phase while the layer beneath is anaerobic and still active.

Also, composting improves manure handling because it reduces the mass and volume of materials, due in part to the loss of water and carbon dioxide during the decomposition process (NRAES, 1992). Temperature, odor, and moisture are good indicators of active composting and adequate aeration (Stentiford, 1996).

Temperature

Under normal conditions in a static composting system, the aerobic decomposition of organic matter generates heat during the following 4 stages in this order: 1) mesophilic, occurring from 10 °C to 40.5 °C; 2) thermophilic, occurring above 40.5 °C; 3) mesophilic; and 4) maturation (NRAES, 1992). For the mesophilic stage, microorganisms are more diverse. Thus, the efficiency of composting decreases. Efficient composting occurs when the materials are within the mesophilic and thermophilic temperature ranges, as this is when heat generation peaks.
before dropping off towards the end of the process. However, temperature observed in CBP barns (Klaas et al., 2010), 36.1 ± 11.0 °C (Black et al., 2013) indicate that the CBP is a semi-compositing system that does not fully cycle the entire compositing process. With bed temperature below 35 to 40, the microbial population is more diverse, reducing the efficiency of compositing (Stentifold, 1996).

**Moisture**

Moisture is critical for biological decomposition because it provides the medium for biological activities (NRAES, 1992). For compost bedded pack barns, urine, feces, and bedding provide the moisture necessary for composting. Efficient biological decomposition occurs at moisture levels of 40% to 60% (NRAES, 1992). Microbial biological activities are affected when moisture is above 65% (wet basis) and cease when moisture falls below 15% (wet basis). Moisture content below 15% (wet basis) stops biological activities because of high matrix suction, which limits water availability to microorganisms (NRAES, 1992). Thus, low moisture content will lead to slower decomposition rates. Moisture levels greater than 60% can reduce aeration because wetter materials are susceptible to compaction (Das and Keener, 1997, Oginni, 2014), reducing free air space in the bed. Das and Keener (1997) found free air space of less than 30% in beds with moisture levels higher than 60% (wet basis).

When free air spaces are reduced, anaerobic conditions develop in the bed leading to low heat generation, low temperature, and odors. Intermediate compounds such as methane, hydrogen sulfide, and organic acids are released when oxygen is insufficient (NRAES, 1992). Visual assessment of moisture involves squeezing the materials, and if water comes out, the materials are too wet. However, if the materials do not feel moist when squeezed, the materials are too dry.
**pH**

pH is a numerical expression of the acidity or alkalinity of a substance. The composting process is sensitive to pH because the microorganisms in composting systems are broad spectrum. Ideal pH during composting lies in the range of 6.5 to 8, and a pH greater than 8 can lead to odors since the higher pH levels foster the conversion of nitrogenous compounds to ammonia. A normal composting process stabilizes the pH of the material, and properly composted materials have a pH close to neutral (NRAES, 1992).

**Carbon-to-nitrogen Ratio**

During composting, microorganisms break down organic matter to obtain energy, nutrients, and protein building compounds to sustain their life processes. Although many elements are needed for sustenance, carbon and nitrogen are the most critical. Carbon is a basic building block and makes up to 50% of a microorganism’s cell mass. Nitrogen forms an essential part of nucleic acids, enzymes, co-enzymes, amino acids, and proteins. Microorganisms need carbon as an energy source and need nitrogen for protein synthesis. The conversion of carbon into energy releases carbon dioxide reducing the C:N ratio. Successful composting occurs at C:N ratios of 25:1 to 30:1 (NRAES, 1992). Microorganisms require 25 to 30 times more carbon than nitrogen. With C:N ratios above 30:1, nitrogen is not sufficient for microbial growth and function, causing the composting process to slow down as the microorganisms require more time to utilize all available carbon. With C:N ratios below 25:1, nitrogen will be in excess. Excess ammonia can be lost as ammonia gas, which produces undesirable odors. However, field experiences with the compost housing show that at low level of C:N (<25:1), ammonia gas could be produced but at too low level to detect.

**Aeration**

The purpose of tilling the composting bed is and to loosen the bed and incorporate air for aerobic microorganisms. Typical composting oxygen requirements are greatest during the
initial stages of the composting process and gradually decrease towards the end. In the presence of oxygen, microorganisms oxidize carbon and release carbon dioxide. Optimal composting occurs at oxygen concentrations of greater than 10% (NRAES, 1992). Although oxygen concentrations of greater than 10% are considered optimal for composting, microorganisms in compost piles can survive at an oxygen concentration of 5% (NRAES, 1992). Oxygen becomes depleted as microbial activities increase (NRAES, 1992), and without the introduction of additional oxygen, the process becomes anaerobic and slows down. The composting bed in the cow resting area is managed to be continuously in the thermophilic/mesophilic temperature range and constant level of oxygen is needed.

Because the aeration rate required for removing heat is 10 times greater than the rate for supplying oxygen, the bedded pack require tillage twice per day at a depth of 25 cm (Janni et al., 2007). Thus, deep tillage (25 cm) is required to incorporate oxygen into the pack and to enhance microbial activities (Leso et al., 2013). Frequent pack tilling is required to prevent compaction and allows for the incorporation of manure into the bedded pack, keeping the surface dry and ensuring that cows stay clean; infrequent tilling, such as once per day or less, leads to dirty cows because the bedding sticks to animals' hides, increasing the exposure of teat ends to pathogens (Shane et al., 2010a), low or no oxygen to support the composting process. Tilling the pack more than 2 times per day may not be economical, however, and during the cold months it can even lead to lower internal temperatures in the pack due to due to evaporative and convective heat loss (NRAES, 1992).

**Economics of Dairy Cattle Housing**

The perceived benefits of a compost bedded dairy housing system include low investment costs, decreased somatic cell count, improved cow cleanliness, improved cow comfort, improved production, ease of completing daily chores, and improved manure handling (Janni
et al., 2007, Black et al., 2013). Galama (2009) found that milk yield per cow is higher, fertility is better, and there are less claw and leg problems in CBP barns than in freestall barns. Because of the soft bed, cows in CBP barns have more freedom of movement, can exhibit when in heat better, and can lie down and get up more naturally (Janni et al., 2007) than when on concrete floors (Haley et al., 2001, Dippel et al., 2009). Lobeck et al. (2011) also reported lower lameness prevalence in CBP barns (4.4%) than in freestalls (15.9%). Barberg et al. (2007a) also found lower lameness in compost bedded pack barns than in freestalls. In most cases, softer surfaces such as in compost bedded pack barns could be more forgiving on the cow’s feet and hocks than is concrete or mats. Also, cows in CBP barns spend less time standing on concrete and do not have restrictions when lying or rising (Janni et al., 2007).

These studies (Barberg et al., 2007a, Black et al., 2013) suggest that CBP barns have enormous potential to improve cow welfare when managed properly than if housed on concrete. However, research notwithstanding, improvements in reproductive performance and in cow comfort are hard to ascertain and slow to present themselves, which only compounds the difficulty of measuring the effects of improved barn conditions. Similarly, claw health tends to improve gradually, lengthening the time it takes to experience the positive effects of improved barn conditions. Producers may find that it takes an interminable amount of time for claw health and fertility to fully benefit from compost bedded pack barns.

Although CBP barns have enormous potential to improve cow performance and welfare, many questions still exist about their management and viability, with one preeminent question being whether the compost bedded dairy barn is suitable in warmer environments such as in Malawi. Climatic conditions, economic factors, and farm management vary; as such, the things that work in one place may not work in the other. High bacteria count, exposure to pathogens, and food contamination from spore-forming bacteria found in CBP barn bedding (Galama et al., 2015) are all critical factors for CBP barns in warmer environments, such as in Malawi.
Conditions that promote efficient composting in compost bedded dairy barns are also favorable for pathogens (Black et al., 2014), and composting temperatures in CBP barns may not destroy pathogens (NRAES, 1992). For example, Streptococci, Staphylococci, and bacilli spores can survive at wider temperature ranges, such as 15–45 °C, 6–48 °C, and 31–76 °C, respectively (Griffiths, 1992, Hardie and Whiley, 1995). Thus, these pathogens (streptococci, staphylococci, and bacilli spores) can survive in weather that is both colder and warmer (Black et al., 2014), making it difficult to destroy them. Additionally, Black et al. (2014) noted that managing for good composting allowed proliferation of coliforms, Staphylococcus, Streptococcus, and Bacillus species in the pack.

With greater temperatures above 45 °C, streptococci and staphylococci will begin to die (Black et al., 2014). However, with these higher temperatures (45 °C), bacilli spores can survive since they are more thermo-intolerant (Griffiths, 1992) than most other bacteria species (NRAES, 1992). Thus, aiming for greater pack temperature (> 45°C) may inevitably select for spore forming bacteria in the bed.

Because cubicle housing as well as compost housing are often built for natural ventilation, they can have increased cost. However, compost barns can have increased building costs because of their low cow occupancy (10 square m per cow). Thus, the efficiency of CBP barns will depend on the cost savings derived from improved animal health, improved animal welfare, improved production, and better manure management (Galama, 2009). However, when compared to freestalls, CBP barns have a lower initial investment cost per cow because they require less concrete, given that a clay base is possible in CBP barns (Janni et al., 2007, Black et al., 2013).

Additionally, CBP barns require less manure-storage facilities because the bedded pack essentially serves as manure storage (Gay, 2009). Also, CBP barns are cleaned only once or twice per yr reducing the cost of labor to clean stalls and may even store to up to 3 years as has
been found (Endres, 2009, Bewley et al., 2013). However, because of on-going annual bedding costs, CBP barns can have an overall annual cost that is higher than that of the cubicle barn. For example, bedding costs ranged from $0.34/d to $0.50/d per cow when bedding was added every 2 to 8 wk (Black, 2013).

Although current recommendations encourage adding the bedding every 2 to 8 wk (Bewley et al., 2013), research (Galama et al., 2015) shows that there can be more flexibility with barn management in CBP barns than there can be in other systems such as freestalls (Leso et al., 2013). Farmers can experiment with when and how much material to add to the bedded pack (Janni et al., 2007).

To provide insights into this situation, a 6-mo study with compost bedded dairy housing technology and conventional cubicle housing was conducted comparing cow performance, udder health, and well-being on a commercial farm located in Lilongwe, Malawi during the rainy and dry season.
Figure 1. 1 Conventional cubicle dairy cattle barn layout (1-2 cows; used with permission from the Department of Animal Health and Livestock Development in Malawi)
Figure 1. Compost-bedded pack barn layout with walkways, drive-by feed manger, and overhang (adapted from Janni et al., 2007)
Chapter Two: Comparison of performance and well-being in dairy cows housed in cubicle housing or compost bedded pack housing: A case study

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Abstract

The objectives were to compare the performance and well-being of dairy cows housed in a compost bedded pack (CBP) barn or a conventional cubicle dairy (CCD) barn and assess the effect of changing from grazing (cows were kept at pasture for 33.33 to 41.67% of the day) to semi-grazing system (cows were kept indoors with access or without access to pasture) on performance and welfare parameters in CCD-housed cows. A 6-mo (March to August) study was conducted on a commercial farm in Malawi in 2017, involving 70 multiparous lactating Holstein-Friesian cows (200 ± 130 DIM; 11.68 ± 3.9 kg of milk/day; mean ± SD). Cows were divided into a CBP or CCD barn. The CCD was located adjacent to the CBP at a walking distance of 50 m. Cows were evaluated weekly for udder health, lameness, hygiene, and hock lesions under the grazing and semi-grazing system during the rainy season (grazing; wk 1 to 4,
Milk yield and somatic cell count (SCC) data were collected during the study. No difference was observed between grazing and semi-grazing system regarding milk yield, lameness, hock lesions, SCC, hygiene, and sub-clinical high SCC prevalence. Sub-clinical high SCC and SCC (x 10^3) were 22% and 48% lower in the CBP barn than in the CCD barn (51.3 ± 0.0 vs 65.7 ± 0.03% and 540.17 ± 47.17 vs 1045.16 ± 49.85 cells/mL, respectively). Hygiene scores were lower in the CBP barn than CCD barn (1.5 ± 0.04 vs 1.8 ± 0.04, respectively). Cows in the CBP barn produced more milk compared with cows in the CCD barn (10.89 vs 9.69 kg/d per cow, respectively). Cows in both housing (CCD and CBP) had no hock lesions. These results indicate that cows in the CBP barn produced more milk, were cleaner, exhibited low SCC, and low sub-clinical high SCC prevalence, than cows in the CCD barn.

Key words: Compost housing, performance, well-being

**Introduction**

Housing systems for dairy cows vary from pasture-based systems to indoor housing systems with limited outdoor access. In Malawi, common systems include 1) systems in which cows are kept at pasture for a large proportion of the day (referred to as “grazing” systems), 2) systems in which cows are kept indoors without outdoor access (referred to as “zero-grazing” systems), and 3) systems in which cows are kept indoors for a large proportion of the day with some outdoor access (referred to as “semi-grazing” systems). (Kawonga et al., 2012, Tebug et al., 2012, Chizonda, 2015). Grazing systems are often used in commercial farms in which grazing is the most cost-effective use of the land (Chagunda et al., 2012).
Grazing has been practiced in commercial farms in Malawi since the 1960s (Chagunda et al., 1999). In recent years, however, semi-grazing and zero-grazing management practices are increasing. In the semi-grazing system, cows are kept indoors with some access to pasture. (Kawonga et al., 2012, Tebug et al., 2012, Chizonda, 2015). This increase in semi-grazing is in part due to a shift in the use of land in peri-urban farming areas or the scarcity of forage during the dry season forcing producers to keep cows in confinement.

When in confinement, cows are mostly fed high levels of concentrate feed and fermentable carbohydrates such as molasses (Chizonda, 2015). To date no study in Malawi has evaluated the effects of semi-grazing system on the performance and welfare in dairy cows. One reason cows may benefit from zero-grazing and semi-grazing systems is because changes in maintenance requirements due to increased confinement can increase the feed efficiency. However, stress because of exposure to excessive manure and mud within housed environments (Tebug, 2012) will generally lead to an increase in energy expended for maintenance. Also, when cows are housed in the CCD barns, they spend more time standing than lying down (13 hours standing vs 9 hours lying down)(Banda, 2014). This low lying time could be due to the effect of exposure to hard lying surfaces (Tebug, 2012). In most cases, if lying surfaces are not comfortable and cows are deprived of sufficient lying time, they can be subject to a decrease in the circulating levels of the growth hormone, a component that is important in milk synthesis (Munksgaard and Løvendahl, 1993).

In contrast, cattle housed on softer surfaces such as in compost bedded pack (CBP) housing show a greater propensity for lying down (Ruud et al., 2010). Further, husbandry practices under zero-grazing or semi-grazing system and a CCD barn design, force cows to walk, increasing the pressure and load on claws. This study hypothesized that housing cows in the CCD barn under a semi-grazing system may have adverse effects on cow performance, udder health, lameness, and hock health.
Mastitis, lameness, and hock lesions are important welfare issues in dairy cattle globally, resulting in productive losses. Mastitis, lameness, and hock lesions can be used to assess the effects of housing and management systems on welfare in dairy cows. Tebug (2012) compared mastitis prevalence in zero-grazing and semi-grazing systems and during the rainy season and dry season. Prevalence rate of mastitis from the survey ranged from 50 to 83.3% (Tebug, 2012). Mastitis was greater in grazing and semi-grazing systems (81.8%) than in zero-grazing systems (54.6%). Mastitis was greater during the rainy season (71.3%) than the dry season (29.4%).

Several studies have examined the effect of housing and management systems on lameness and hock lesions. Hock lesions are associated with the type of flooring. Hock lesions are greater on concrete flooring than on softer lying surfaces (Gomez and Cook, 2010, Lobeck et al., 2011). Hock lesions and skin damage are greater on hard lying surfaces such as concrete because concrete is abrasive and unyielding (Vokey et al., 2001).

Lameness is associated with housing and management. Lameness appears to be greater on hard surfaces such as concrete than on softer lying surfaces (Venegas et al., 2006) and in cubicle housing than in straw-yard housing (Somers et al., 2003). Lobeck et al. (2011) noted that lameness prevalence was significantly high in freestalls (15.9 P<0.01) than in compost bedded pack barns (4.4%). Tebug (2012) found a lameness prevalence of 2.7% in dairy cattle in cubicle housing with concrete, brick, or clay flooring. This lameness (2.7%) could have been due to exposure to slurry or the effect of concrete (Tebug, 2012). Sanitation in animal housing has an effect, not only on udder health (Schreiner and Ruegg, 2003, Ruud et al., 2010), but also on hoof health (Ahrens et al., 2011).

Cleaner housing conditions should result in cleaner cows, decreasing the risk of both mastitis and hoof disorders such as heel horn erosion (Schreiner and Ruegg, 2003, Ahrens et al., 2011). Also, access to pasture in zero-grazing or semi-grazing systems might minimize the negative effects that concrete has on hoof health (Hernadez-Mendo et al., 2007).
The objectives of this study were to assess the influence of housing and management systems on milk production, udder health, lameness, hygiene, and hock lesions. A 6-mo study with two loose housing systems (compost bedded pack housing or a conventional cubicle dairy housing) and two management systems (grazing vs semi-grazing systems) with repeated measurements was conducted to assess the effect of the housing and semi-grazing system.

**Materials and Methods**

**Study location**

This study was conducted at Katete commercial dairy farm located in Lilongwe agro-ecological region at latitude 13.9ºS and longitude 33.6ºE in central Malawi (Southeast Africa) from March 1 to August 30, 2017. Agro-ecological regions are defined by physiography, climate, and land suitability classes (Venema, 1990). Lilongwe agro-ecological region in central Malawi has a sub-tropical climate which is characterized by two distinct seasons: the rainy season (November to April) and dry season (May to October) (Malawi Government, 2001, Vincent et al., 2014). The rainy season stretches from November to April, during which 95% of the annual precipitation takes place. Minimum, mean, and maximum temperature-humidity index (THI) at this location for the 6-mo period were 58, 72, and 66, respectively. This study was carried out during the rainy season (March to April) and dry season (May to August). Soils in the study area are mostly alfisols with loamy sand texture and are moderately acidic (Snapp, 1998).

**Design of the Study**

A single-system study was designed to assess the effect of housing systems, conventional cubicle dairy (CCD) housing and compost bedded pack (CBP) and grazing vs semi-grazing systems on dairy cattle performance and welfare in one commercial dairy herd in Lilongwe, Malawi (Southeast Africa). Two different management systems; grazing system (“systems in
which cows are kept at pasture for a large proportion (8 to 10 h; 33.33 to 41.67% of the day) of the day) and semi-grazing system (systems in which cows are kept indoors with (16.67% of the day) or without outdoor access) were maintained on the pasture-based farm during the rainy season (grazing; wk 1 to 4, semi-grazing; wk 6 to 9) and dry season (grazing; wk 11 to 16), semi-grazing; wk 18 to 23). To examine the influence of housing (CCD vs CBP) on the performance and welfare in dairy cows, cows were evaluated at weekly intervals for lameness, hock lesions, SCC, and hygiene. The scores for lameness, hock lesions, and hygiene for the CCD barn and CBP barn were calculated from the mean value of the individual evaluations of cows in the CCD barn and CBP barn when cows were in semi-grazing system during the rainy season (wk 6 to 9) and dry season (wk 18 to 23).

To examine the influence of management systems on the performance and well-being in CCD-housed dairy cows, data were collected under a grazing system (systems in which cows are kept at pasture for a large proportion (8 to 10 h; 33.33 to 41.67% of the day) of the day) and semi-grazing system (systems in which cows are kept indoors with outdoor access or without outdoor access). Data of CCD-housed cows before and after changing to semi-grazing system during the rainy season (wk 1 to 4; grazing, wk 6 to 9; semi-grazing) and before and after changing to semi-grazing system during the dry season (wk 11 to 16; grazing, wk 18 to 23, semi-grazing) were examined.

Animal Management

Seventy multiparous mid-lactation, Holstein-Friesian cows (200 ± 130 DIM; mean ± SD) were involved in the study. Cows were randomly allocated to the two barns: the CBP barn (n = 35) or CCD barn (n = 35). These cows were balanced for DIM (200 ± 130), and milk production (11.68 ± 3.9kg/day). Depending on the management decisions such as culling, eleven cows were removed during the 6-mo study.
The main reasons for cows to be removed were breeding (95%) and sick (5%). Data of 58 cows were included in the analysis (CCD; n = 27, CBP; n = 31). The CCD barn was located directly adjacent to the CBP at a walking distance of 50 m. Cows in both the CBP barn and CCD barn were managed on pastures of Rhodes grass (*chloris gayana*), Bermuda grass (*cynodon dactylon*), and Guinea grass (*panicum maximum*).

Each group (CCD and CBP) was randomly allocated to pastures under the farm set-stocking management throughout the study with short rotations. Cows accessed pastures for 8 to 10 h (33.33 to 41.67% of the day) under the grazing system. Cows accessed pastures for approximately 4 h (16.67% of the day) under the semi-grazing system (3 h after morning milking and 1 h after evening milking). The two barns (CCD and CBP) received similar quantity of Napier grass (*pennisetum purpureum*) mixed with maize bran and molasses under the semi-grazing system. Napier grass (*pennisetum purpureum*) mixed with maize bran and molasses were provided x 2 a day (1200 h and 1700 h). A concentrate prepared for all cows was provided during milking. Each cow was given 4 kg of concentrate at each milking throughout the study.

All cows were milked twice a day (0200 h and 1400 h) in a 2 x 12 milking parlor. The milking procedure was identical for each group. The milking procedure involved washing teats with water, fore-stripping, pre-dipping, drying of teats with a cloth, and milking unit attachment. Post dip was rarely applied after removing milking unit. All milking personnel were trained in milking hygiene practice before the study. Individual cow milk was collected in milk churns and weighed using a scale. The study farm used a foot bath (copper sulphate) which was changed after evening milking.
Pasture management

A grazing system was implemented on the commercial dairy farm, with 7 pasture zones, measuring 41 ha. All cows were moved from one pasture zone to the next depending on plant height and management decision. Plant species including Rhodes grass (*chloris gayana*), Napier grass (*pennisetum purpureum*), Bermuda grass (*cynodon dactylon*), sorghum, and Guinea grass (*panicum maximum*) were grown on the farm. The plants were grown on alfisols with loamy sand texture and moderately acidic (Snapp, 1998). Pastures were fertilized with liquid manure.

Housing Facilities for Study Cows

Conventional cubicle dairy (CCD) housing and compost bedded pack (CBP) housing design features are shown in Figure 2.1 and 2.2. The CCD and CBP barns were both naturally ventilated with high side walls. The CCD and CBP barns were both oriented east to west to reduce exposure of cows to the sun. The basic flooring in both housing system (feed alley, feed manger, and exercise areas) had identical concrete. The management and care of the concrete floors (feed manger and exercise area in the CCD barn and feed alley and exercise area in the CBP barn) during the rainy season and dry season was closely monitored by the study personnel to ensure that floors were managed identically. Visual inspection of the housing environments was performed 3 times/wk—on Monday during weekly visits and on two additional days during the week. The concrete floors in the CCD barn exercise area and feed manger and the concrete feed alley in the CBP barn were manually cleaned daily at 0800h by moving manure with a hand-held scraper while cows were at pasture.

Before the study, all farm personnel managing the CCD and CBP barns and all milking personnel were trained on milking hygiene practices. The CCD barn design included a central feeding area (feed manger and automated waterers), concrete exercise area, and two rows of sand and straw bedded stalls on either side of the feeding area. The CCD barn had 150 freestalls.
Thirty-five cows were managed in the CCD barn. Therefore, at least 4 stalls were available to each cow. Mean (± SD) bed length and width were 2.28 ± 0.06 m and 1.68 ± 0.23 m, respectively. The CCD stalls were bedded with sand (which worked as a stall base) and a layer of straw bedding. The straw bedding was replenished once weekly, whereas the sand which worked as a stall base was not replenished during the 6 mo study. The mean (± SD) sand and straw bedding thickness was 33.74 ± 0.04 cm. The stall length (m), width (m), and stall bed (cm) were measured using a laser (Robert Bosch Tool Corporation, Mt. Prospect, IL, USA).

The CBP barn design included an open composted pack, feed alley, and exercise area. Waterers were located within the feed alley. The feed alley and the exercise area had concrete flooring. A 1.2 m high retaining wall separated the pack from the feed alley.

The pack lying space per cow was 9.71 m². The bedded pack length (m) and width (m) were measured using a laser (Robert Bosch Tool Corporation, Mt. Prospect, IL, USA). The composted pack was bedded with sawdust. The wood sawdust used: soft wood sawdust of pines and hard wood sawdust, were obtained during milling operation from Duroblock sawmill in Lilongwe, Malawi. The sawdust was sun-dried before storage under shed or before adding to the bedded pack. The bedded pack was tilled twice a day using a cultivator (Janni et al., 2007). The CBP was initially bedded with 50 cm of sawdust (Galama, 2009). Sawdust bedding was added based on the moisture guideline for composted beds (40 to 60%) (NRAES, 1992).

**Data Collection**

**Milk Production**

Individual milk yields were recorded daily. Milk yield data for each cow was averaged to provide a weekly average per cow.
Animal Welfare Measurements

Cow hygiene

To assess the cleanliness of the cow, hygiene scoring was used to record the degree of manure contamination on udder, lower leg, and upper leg and flank using a 1 to 4 scale (1 = clean, 2 = moderate dirt, 3 = plaques of dirt with hair visible, 4 = confluent plaques of dirt with no hair visible) hygiene scoring system (Cook and Reinemann, 2007). Each site (udder, lower leg, and upper leg and flank) was assessed separately and was defined as 1 = clean, 2 = moderate dirt, 3 = plaques of dirt with hair visible, 4 = confluent plaques of dirt with no hair visible (Cook and Reinemann, 2007).

Hock Lesions Prevalence

Hock health is a good indicator of cow comfort and abrasiveness of bedding material. All cows in each housing system were visually scored for hock lesions weekly by the same observer in the parlor before milking unit attachment using 1-3 scale (1 = no lesions, 2 = mild lesion [hair loss], and 3 = severe lesion [swollen hocks with or without hair loss]). The presence or absence of injuries to the hocks was scored. The presence of swellings (filling or enlargement of the joint) and scratches (exposed or broken skin) were recorded for both hocks. Hock lesion prevalence was calculated as the total number of cows with a hock lesion score greater than two divided by the total number of animals scored (Lobeck et al., 2011).

Lameness Prevalence

Cows were evaluated weekly for lameness using a 1-3 locomotion scoring system (1 = sound: no obvious gait abnormality, cows walk comfortably with long strides; 2 = mildly/moderately lame: visible gait abnormality, which may include shortened stride length, head bob, and/or arching of the back, cows appear uncomfortable and walk stiffly, but the affected limb is not
necessarily obvious; 3 = severely lame: obvious gait abnormality, which may include shortened stride-length, prominent head bob, and/or pronounced arching of the back, cow will be hesitant to bear weight on the affected limb, and walking will be extremely difficult) (NAHMS, 2015).

Cows were scored by the same observer as cows were exiting the parlor and as they walked on a flat area (Barberg et al., 2007a). A locomotion score ranging from 1 (no gait abnormality) to 3 (severely lame) was assigned to all cows in the CCD barn or CBP barn. For each housing system (CCD and CBP), the prevalence of clinical lameness was calculated by dividing the number of cows with a locomotion score of 3 by the total number of cows scored each week (Barberg et al., 2007a).

**Somatic cell counts**

Somatic cell count is an indicator of udder health. Composite milk samples were collected weekly and analyzed for somatic cell count. Individual milk samples were drawn aseptically (Hogan et al., 1989a) from individual quarters. Teat ends were washed and dried using a clean cloth; teats were fore-stripped, pre dip was applied and removed with a clean cloth, and teat end were cleaned with 70% isopropyl alcohol swab before drawing a 5 ml sample. Quarter milk samples were pooled and mixed thoroughly before drawing a single sample (10 ml) for SCC analysis using an Ekomilk scan somatic cells analyzer (Ekomilk scan, BULTECHC 2000, Sweden).

Milk samples were analyzed individually on the somatic cells analyzer. The somatic cell analyzer was cleaned using deionized water between each sample. Milk samples were analyzed for SCC within three hours of milking. Composite milk SCC of ≤200,000 cells/mL was a threshold value for cows with all quarters free of subclinical mastitis (Smith, 1997).
Individual cow milk SCC was log transformed to obtain a linear score using the following equation: SCC = Log$_2$ (SCC/100000) +3). The linear score was back transformed for interpretation. Sub-clinical high SCC was calculated as the number of animals with a test SCC >200,000 cells/mL divided by the total number of animals scored each week (Barberg et al., 2007a).

**Milk bacteria**

Quarter milk samples were aseptically collected as described by Hogan et al. (1989a) from cows with SCC >200,000 cells/mL or cows with clinical mastitis. A clinical mastitis case was defined as cows with visual signs of inflammation including swollen udder, redness or heat, abnormal milk, and/or presence of clots in milk. Milk samples collected during the rainy season and dry season were cultured for isolation of bacteria. Serial 10-fold dilutions were made for each sample to ensure that one of the final plates would have 30 to 300 colonies for bacterial enumeration. A 1:10 dilution was prepared by placing 1 ml of milk sample into 10 mL of distilled water. Aliquot of 0.01 ml (10 µL) were streaked onto one-half of MacConkey agar and blood agar plates using a sterile swab. Plates were placed in an inverted position in an incubator at 35 °C for 24 h to 48 hours.

Gram stains were performed to differentiate gram-positive and gram-negative bacteria. *Streptococcus agalactiae* were identified based on growth on blood agar, biochemical tests including hemolysis on blood agar, catalase test, acid production in broth containing different carbohydrates and Lancefield’s classification by means of agglutination tests (group B: *Streptococcus agalactiae*). *Streptococcus dysgalactiae* were identified based on growth on blood agar, catalase test, and Lancefield’s classification by means of agglutination tests (group C, *Streptococcus dysgalactiae*). *Klebsiella spp* were identified based on growth on blood agar (moist and mucoid) and growth on MacConkey agar (pink-yellow mucoid colonies), and Triple Sugar Iron reaction (acid slant, acid butt, and gas production).
To perform antimicrobial sensitivity tests for *Streptococcus agalactiae*, *Streptococcus dysgalactiae*, and *Klebsiella* spp, discs were applied on blood agar and inoculated with the pathogens. The discs were incubated at 37°C for 16-18 hours. After 18 h, the discs were viewed for zones of inhibition (Holt et al., 1993).

**Statistical Analysis**

Data collected a week after cows changed from grazing to semi-grazing system in each season were removed before being subjected to statistical evaluation. Continuous variables such as cow hygiene, somatic cell count, and milk yield in this study were analyzed as repeated measurements using the PROC Mixed Procedure of SAS (version 9.3, SAS Institute Inc., Cary, NC) using a restricted maximum likelihood model (REML) according to the following model;

\[
Y_{ijk} = \mu + Hi + Mj + Sk + Hi x Sk + \varepsilon_{ijk}
\]

where \(Y_{ijk}\) = an individual data point, \(\mu\) = overall mean, \(Hi\) = housing system (i = 1 to 2), \(Mj\) = management system (j = 1 to 2), \(Sk\) = season (k = 1 to 2), \(Hi \times Sk\) = interaction H x S (i x k), \(\varepsilon_{ijk}\) = residual error. To account for the individual variation of the cows, a repeated statement was included. The model for milk production included the DIM as a covariate and was adjusted for mastitis. Different covariance structures were used and the one with lower Akaike information criterion was chosen as the better fit for the mixed model.

In this study, cows were evaluated at weekly intervals for lameness, hock lesions, SCC, and hygiene. The scores for lameness, hock lesions, and hygiene for the CCD barn and CBP barn were calculated from the mean value of the individual evaluations of cows in the CCD and CBP barns when cows were in semi-grazing system during the rainy season (wk 6 to 9) and dry season (wk 18 to 24).
The effect of the management system (grazing vs semi-grazing system) on cow hygiene, somatic cell count, sub-clinical high SCC, lameness, hock lesions, and milk yield was investigated for cows housed in the CCD barn before and after changing to semi-grazing system during the rainy season (wk 1 to 4; grazing, wk 6 to 9; semi-grazing) and the dry season (wk 11 to 16; grazing, wk 18 to 23, semi-grazing).

Sub-clinical high SCC prevalence (cows with a test SCC >200,000 cells/mL) was analyzed as a repeated measure using the PROC GENMOD procedure in SAS. PROC GPLOT in SAS was used to generate plots of sub-clinical high SCC prevalence (proportion of cows with SCC > 200000 cells/mL) rates. A simple percentage evaluation was performed for the analysis of the detected bacteria in milk samples during rainy season and dry season. LSMEANS option in SAS (version 9.3, SAS Institute Inc., Cary, NC) was used to test differences between means. Statistical significance was declared at $P < 0.05$. Tendencies were reported at $0.05 < P < 0.10$. Data were checked for normality of variance by visual plots. Analysis of outliers was performed using box plots. Somatic cell counts were log transformed to obtain a linear score (Barberg et al., 2007a).

**Results**

**Cow hygiene**

Table 2.1 shows the average hygiene score for the CCD and CBP barns. Hygiene scores were lower in the CBP barn than CCD barn (1.5 ± 0.04 vs 1.8 ± 0.04, respectively, $P < .0001$). Mean hygiene score for the CCD barn and CBP barn during the rainy and dry seasons is described in Table 2.2. Housing system by season interaction on the hygiene score was detected ($P < .0001$), indicating that hygiene scores were highest in the CCD barn during the rainy season. Mean hygiene score during the rainy season was lower for the CBP barn compared with the CCD barn ($P < .0001$, Table 2.2).
Mean hygiene score during the dry season did not differ between the CBP and the CCD barn ($P > 0.05$, Table 2.2). The mean hygiene score for the CCD barn was lower during the dry season compared with the rainy season (1.65 ± 0.06 vs 1.97 ± 0.07, respectively, $P < 0.0001$); however, cows were still moderately dirty during the dry season (hygiene score = 1.65 ± 0.06 on a 1 to 4 scale; 1 = clean, 4 = dirty). The mean hygiene score for the CBP barn did not differ between the rainy season and dry season (1.57 ± 0.08 vs 1.50 ± 0.07, respectively, $P > 0.05$, Table 2.2).

Average hygiene scores for the two management systems (grazing or semi-grazing system) is described in Table 2.3. Mean hygiene scores for the CCD barn during the rainy season under grazing and semi-grazing systems were 1.96 ± 0.07 and 1.97 ± 0.06, respectively ($P > 0.05$, Table 2.3). Mean hygiene scores for the CCD barn during the dry season under grazing and semi-grazing systems were 1.96 ± 0.07 and 1.65 ± 0.06, respectively ($P < 0.05$, Table 2.3).

**Udder health**

Average SCC for the two housing systems (CCD and CBP) during this study is described in Table 2.1. Figure 2.3 shows trends in SCC during the rainy and dry season. Somatic cell count was used as an indicator of udder health. The mean SCC for the CBP barn was 540,168 ± 47,170 cells/mL, which is 48.32% lower than the mean SCC in the CCD barn (1,045,162 ± 49,825 cells/mL). Average SCC for the CCD barn and the CBP barn during the rainy and dry season is described in Table 2.2. Housing system by season interaction on SCC was not detected ($P > 0.05$). The mean SCC was lower for cows in the CBP barn compared with cows in the CCD barn during the dry season ($P = 0.002$, Table 2.2, Figure 2.3).

No difference between housing was observed in the mean SCC during the rainy season ($P > 0.05$, Table 2.2). The mean SCC for CCD barn was lower during the rainy season compared with the dry seasons (855,754 ± 119,257 and 1,016,901 ± 83,054 cells/mL, respectively, $P = 0.002$, Table 2.2, Figure 2.3). No difference between seasons (rainy and dry season) was observed in the mean SCC for the CBP ($P > 0.05$, Table 2.2, Figure 2.3). Average SCC for the
CCD for the two management systems (grazing or semi-grazing system) is described in Table 2.3. The mean SCC for the CCD barn did not differ between grazing and semi-grazing systems during the rainy season (1,143,189 ± 102,238 and 855,754 ± 99,633 cells/mL, \( P > 0.05 \), respectively) and the dry season (1,025,764 ± 79,666 and 1,016,901 ± 83,054 cells/mL, respectively, \( P > 0.05 \)).

Average sub-clinical high SCC prevalence for the CCD barn and CBP barn is described in Table 2.1. The average sub-clinical high SCC prevalence for the CBP barn was 51 ± 0.02%, which is 22.72% lower than 66 ± 0.02% for the CCD barn (\( P < 0.05 \)). Average sub-clinical high SCC prevalence for the CBP barn during the rainy and dry season is described in Table 2.2. Housing system by season interaction on sub-clinical high SCC prevalence was not detected (\( P > 0.05 \)). The mean sub-clinical high SCC prevalence was lower for cows in the CBP barn compared with the CCD barn during the rainy season (\( P < 0.05 \), Table 2.2). The mean sub-clinical high SCC prevalence did not differ between the CBP barn and the CCD barn during the dry season (\( P > 0.05 \), Table 2.2). Sub-clinical high SCC prevalence during the rainy and dry seasons for the CBP barn was 52 ± 0.05 and 56 ± 0.04%, respectively; no difference was observed between seasons (\( P > 0.05 \)). Sub-clinical high SCC prevalence during the rainy and dry season for the CCD barn was 67 ± 0.03 and 64 ± 0.03%, respectively; no difference was observed between seasons (\( P > 0.05 \)).

Average sub-clinical high SCC prevalence for the CCD barn under the grazing and semi-grazing systems is described in Table 2.3. The average sub-clinical high SCC prevalence for the CCD barn during the rainy season did not differ between grazing and semi-grazing systems (68 ± 0.03 and 63 ± 0.03%, respectively, \( P > 0.05 \)). The average sub-clinical high SCC prevalence for the CBP barn during the dry season did not differ between grazing and semi-grazing systems (67 ± 0.03 and 64 ± 0.03%, respectively, \( P > 0.05 \)).
**Hock lesions**

Hock lesion prevalence (proportion of cows with a hock lesion score > 2) was 0.00 and 0.00% for the CCD barn and the CBP barn, respectively, indicating that cows in both housing system (CCD and CBP) had excellent hock health.

**Lameness**

Average clinical lameness prevalence in the two housing systems (CCD and CBP) is presented in Table 2.1. The average clinical lameness prevalence did not differ between the CCD and CBP barns (0.69 ± 0.01 and 0.04 ± 0.01%, respectively, \( P > 0.05 \)). Average lameness prevalence for the two housing systems (CCD and CBP) during the rainy and dry season is described in Table 2.2. No housing by season interaction on lameness prevalence was detected. For the CCD barn, lameness prevalence did not differ between the rainy and dry season (0.11 ± 0.01 vs 0.56 ± 0.01%, respectively, \( P > 0.05 \), Table 2.3). For the CBP barn, lameness prevalence did not differ between the rainy and dry season (0.01 ± 0.01 vs 0.61 ± 0.01%, respectively, \( P > 0.05 \), Table 2.2).

Average clinical lameness prevalence for the CCD barn under grazing and semi-grazing systems is described in Table 2.3. Clinical lameness prevalence did not differ between grazing and semi-grazing systems during the rainy season (1.94 ± 0.01 vs 0.16 ± 0.01%, respectively, \( P > 0.05 \)). Clinical lameness prevalence did not differ between grazing and semi-grazing systems for the dry season (0.11 ± 0.01 vs 0.56 ± 0.01%, respectively, \( P > 0.05 \)).

**Milk production**

Mean milk yield for the two housing systems (CCD and CBP) when cows were in semi-grazing systems during the rainy season (wk 6 to 9) and dry season (wk 18 to 24) is described in Table 2.1. Figure 2.4 shows the trend in milk yield of cows housed in the two housing systems (CCD and CBP).
The mean milk yield of cows housed in CBP barn was greater compared to mean milk yield of cows housed in the CCD barn (10.9 ± 0.40 vs 9.69 ± 0.46 and kg/day per cow, respectively, $P < 0.05$). The biggest difference between the 2 housing systems (CBP and CCD) was observed during the dry season ($P = 0.003$, Figure 2.4). Average milk yield (kg/day per cow) for the two housing systems (CCD and CBP) during the rainy and dry season is described in Table 2.2. Housing by season interaction on milk yield was not detected ($P > 0.05$). No difference between housing systems (CBP and CCD) was observed in the mean milk yield during the rainy season (10.06 ± 0.56 vs 9.48 ± 0.63, respectively, $P > 0.05$). The mean milk yield for cows housed in the CBP barn was greater compared with milk yield of cows in the CCD during the dry season (11.22 ± 0.56 vs 9.81 ± 0.56 kg/day per cow, respectively, $P < 0.05$, Table 2.2, Figure 2.4).

Mean milk yield did not differ between the rainy and dry seasons for the cows housed in the CCD barn (9.48 ± 0.63 vs 9.81 ± 0.56 kg/day per cow, respectively, $P > 0.05$). Mean milk yield for cows housed in the CBP was 10.34% greater during the dry seasons compared with the rainy season (11.22 ± 0.56 vs 10.06 ± 0.56 kg/day per cow, respectively, $P = 0.05$). Average milk yield (kg/d per cow) for the CCD with cows managed under grazing and semi-grazing systems is described in Table 2.3. The mean milk yield of cows housed in the CCD under grazing and semi-grazing systems was 9.09 ± 0.61 and 9.48 ± 0.62 kg/day per cow, respectively ($P > 0.05$) during the rainy season. The mean milk yield of cows housed in the CCD barn under grazing and semi-grazing systems was 10.32 ± 0.56 and 9.81 ± 0.56 kg/day per cow, respectively ($P > 0.05$) during the dry season.

**Milk bacteria**

Table 2.4 represents the percentage of bacteria isolated from milk samples of lactating dairy cows during the study. Bacteria varied between seasons (rainy and dry season). *Klebsiella* species were present in 27 of 50 milk samples during the rainy season. *Klebsiella* species during the dry season were in 36 of the 50 milk samples.
*S. dysgalactiae* was present in 14 of 50 milk samples during the rainy season; *S. agalactiae* were present in 7 of 50 milk samples during the rainy season. *S. dysgalactiae* were present in one out of 50 milk samples during the dry season. *S. agalactiae* were not present in milk samples during the dry season. Contagious and environmental pathogens in milk samples during the rainy season were 14% and 82%, respectively. Results of antimicrobial sensitivity test for *Klebsiella* spp, *S. dysgalactiae*, and *S. agalactiae* showed that *Klebsiella* spp were mostly sensitive to chloramphenicol and streptomycin. *S. agalactiae* were mostly sensitive to erythromycin, chloramphenicol, and fusidic acid. *S. dysgalactiae* were sensitive to a wide large of antibiotics including; streptomycin, erythromycin, chloramphenical, tetracycline, novobiocin, and erythromycin.

**Discussion**

The effects of housing and management systems on performance and welfare in dairy cows were examined on a single farm. Therefore, the results should not be generalized to a larger population. This study design was chosen for the purposes of obtaining data on the compost bedded pack barn, which is a newer housing concept (Janni et al., 2007). This study provided a detailed insight into the performance of lactating dairy cows housed in the compost bedded pack barn with access to pasture under semi-grazing system. These useful insights can be researched further using more definitive assessments.

The subjects in the study of the effect of management system (grazing vs semi-grazing system) for the conventional cubicle housing served as their own control, thereby providing detailed insight into the newer management system (semi-grazing system). Further investigations on the semi-grazing system are required. For example, the results of the present study can be combined in a meta-analysis to improve the power.
In terms of the welfare and performance of dairy cows, the present study revealed low hygiene scores, lower SCC, lower mastitis prevalence, and improved milk yield due to housing cows in compost bedded dairy barn. This supports research comparing the welfare and performance of cows housed in CBP barns and freestalls (Barberg et al., 2007, Lobeck et al., 2012, Black et al., 2013), in which the benefits of housing cows in the CBP barn such as increased milk yield, lower mastitis, SCC, and hygiene scores were observed.

This study showed that hygiene scores were lower in the CBP barn than the CCD barn during the rainy season. Although hygiene scores of cows housed in the CCD barn decreased with season, cows were still moderately dirty with a score of 1.65. Because cows in CCD barns stand for most part of the day (13 h) (Banda, 2014), which can lead to high accumulation of urine and feces, moisture on concrete or in the bedding can result in dirty cows (Tebug, 2012). Rain water during the rainy season, exacerbates this effect, resulting in high prevalence of mastitis (Tebug, 2012). The current results suggest that cows kept in the CBP barn were cleaner throughout the study with mean hygiene score of 1.5 ± 0.05 compared with cows in the CCD with mean hygiene score of 1.80. Black et al. (2013) found hygiene scores of 2.2 ± 0.7 in cows housed in a CBP barn after transitioning from tie stalls or pasture and demonstrated that the CBP barn can be a great environment for cows when properly managed.

The mean hygiene score for the CBP barn (1.5 ± 0.05) was lower than hygiene scores observed by Barberg et al., (2007a), 2.66; Black et al., (2013), 3.1; and Lobeck et al., (2011), 2.77. Compared with cows in the previous studies by Barberg et al., (2007a), Lobeck et al., (2011), and Black et al., (2013), cows in the present study were kept indoors with some access to pasture (16.67% of the day) under a semi-grazing system. Cows in the studies by Barberg et al., (2007a), Lobeck et al., (2011), and Black et al., (2013) were kept indoors without outdoor access after transitioning from pasture or freestalls.
Cows in confinement tend to have higher hygiene scores compared with cows in grazing systems, which could be related to reduced cleanliness within housed environments (Klaas and Bjerg, 2012, Tebug, 2012). For example, during winter, most producers find it difficult to maintain optimal composting conditions in the CBP barns, resulting in slower drying rate and dirtier cows (Barberg et al., 2007a, Lobeck et al., 2011). Similar to other studies (Barberg et al., 2007a, Lobeck et al., 2011, Black et al., 2013), mean SCC and sub-clinical high SCC prevalence was lower in the CBP barn compared with the sand and straw bedded CCD barn. These results, however, are contrary to results of Eckelkamp (2014), who reported no difference in mean SCC between animals housed in compost bedded dairy barns and sand bedded freestalls. A known consequence of using organic bedding in the CBP barn and other animal housing systems is the risk of exposure of teat ends to disease pathogens. With proper sanitation, however, as shown in our results, the bedding does not stick to the udder and feet, resulting in clean cows.

Schreiner and Ruegg (2003) demonstrated that when housed on drier surfaces, cows display low rates of intramammary infections. Cleanliness of the lower rear legs, feet, and udder has a great influence on somatic cell counts. It is important therefore, to maintain clean, comfortable, and dry lying surfaces and environments that promote cow cleanliness and enhances cows' defense systems to help resist diseases. Compared with the study by Eckelkamp, (2014), the sand base in the cubicle housing was not replenished during the 6 mo study. In this context, our results need a critical interpretation and attention should be focused on the circumstance of CCD barn stall grooming. Although, inorganic bedding reduces exposure to pathogens as compared to organic bedding (Zdanowicz et al., 2004) and unused straw bedding contain less \textit{Streptococcal} species than other types of beddings, concentration of bacteria species such as \textit{Streptococcal} species in inorganic bedding increases over time with increased contamination from urine and manure (Hogan et al., 1989b).
The mean sub-clinical high SCC prevalence for both the CBP and CBP barns under semi-grazing systems was below the average sub-clinical high SCC prevalence in cows under grazing and semi-grazing systems in Malawi (81.80%) (Tebug, 2012). The mean sub-clinical high SCC prevalence for both the CCD and CBP barns during the rainy season (67 ± 0.03 and 56 ± 0.04%, respectively) was below the average sub-clinical high SCC prevalence in cows during the rainy season in Malawi (71.3%). However, the high sub-clinical SCC prevalence for the CBP (51, se = 0.02%) was greater than 27.7% (Barberg et al., 2007a) and 33.4% (Lobeck et al., 2011) for compost bedded dairy barns.

The mean somatic cell count for the CBP barn (540,168 ± 47,170 cells/mL) was greater than 325,000 cells/mL (Barberg et al., 2007a), 425,000 cells/mL (Shane et al., 2010), and 354,000 cell/mL (Leso et al., 2013) for compost dairy barns. Overall, no difference between the rainy and dry season on the SCC was observed in the CBP barn (Table 2.2, Figure 2.3). Several studies (Barberg et al., 2007, Black et al., 2013) have shown that SCC improves over time for cows after transitioning into compost barns. In the current study, the CBP pack average, minimum and maximum bed temperatures were 30.89 ± 7.5°C, 24°C, and 43.3°C, respectively (data not shown). At this mean bed temperature (30.89 ± 7.5°C), microbial diversity increases reducing the efficiency of composting. Efficient composting occurs within the mesophilic and thermophilic temperature ranges. Managing CBP for good composting allows proliferation of pathogens such as coliforms, Staphylococcus, Streptococcus, and Bacillus species in the pack (Black et al., 2014). However, with a proper balance of organisms in the compost bed, organisms might competitively inhibit pathogens in the feces (Petzen et al., 2009).

Because compost bedded pack performance and milk hygiene practices have a great influence on somatic cell count on CBP farms, SCC tend to be low with a higher degree of pack management coupled with excellent milking hygiene practices (Black et al., 2013). Excellent pre-milking cow prep incorporates the following practices: use of 1 cloth per cow, fore-
stripping, pre-dipping, and post-dipping. In the current study, the use of water to clean teats and dirty udders might have negatively affected the level of sub-clinical high SCC prevalence. Also, whereas pre-dipping is effective in reducing clinical mastitis, post-dipping is important in the management of contagious pathogens associated with sub-clinical mastitis.

Contrary to results of Eckelkamp (2014) who found no difference in SCC between CBP barns and sand bedded freestalls (241,716 and 228,796 cells/mL, respectively), SCC in the CBP was significantly \( P < 0.05 \), Table 2.2) lower compared with the CCD during the dry season.

The mean SCC for cows housed in the CCD barn was $> 1,00,000$ cells/mL during both the rainy and dry seasons, which may indicate udder infection with major pathogens. With SCC $> 1,00,000$ cells/mL, there is a risk that milk yield will decrease due to increasing SCC (El-Tahawy and El-Far, 2010).

Milk samples were cultured to identify pathogens associated with high SCC on the farm. The percentage of contagious pathogens in milk samples during the rainy season was lower (14%) compared with environmental pathogens (82%). Environmental pathogens were lower (73%) during the dry season compared with the rainy season (82%). Tebug (2012) also found a lower percent (14.3%) of contagious pathogens compared with environmental pathogens (85.7%) in California Mastitis Test (CMT) positive milk samples. *Klebsiella* species were the most common bacteria isolated in milk samples during both seasons (rainy and dry season, Table 2.4). *Klebsiella* species were lower during the rainy season than during the dry season (27 of 50 samples and 36 of 50 samples, respectively, Table 2.4). The results are consistent with other studies (Lobeck et al., 2012), showing that *Klebsiella* species are greater during the dry season compared with other seasons.

Cows housed in both the CBP barn and CCD barn face the risk of increased *Klebsiella* species, an environmental pathogen, during the dry season. However, producers could counteract the adverse effect of this by maintaining a dry resting surface, which has been shown to minimize
teat end exposure to pathogens (Black et al., 2014). The use of kiln dry shavings in CBP barns could be an option. Sensitivity tests revealed that Klebsiella species were mostly sensitive to chloramphenical. *S. agalactiae* and *S. dysgalactiae* were sensitive to tetracycline, novobiocin, and chloramphenicol. Because clinical Klebsiella mastitis is resistant to antibiotics, keeping cows healthy is critical in managing Klebsiella species because well-nourished cows in stress free environments will have stronger immune systems and will be capable of fighting off infections.

In this study, no hock lesions were observed in cows in both housing (CCD and CBP), similar to other studies with cows housed on softer surfaces such as compost bedded packs, straw yards, or sand bedded stalls (Haskell et al., 2006a, Lobeck et al., 2011). Softer surfaces might cause less damage on the hocks than do other surfaces such as concrete and mats (Haskell et al., 2006a, Lobeck et al., 2011). Gibbons et al. (2010a) also found no hock lesions in cows housed in the CCD barns and concluded that cows housed in the CCD barns exhibited a high standard of welfare. Eckelkamp (2014) found no hock lesions in compost bedded pack barns in Kentucky. Contrary to results of Lobeck et al. (2011), this study showed that lameness and hock lesions were not different in cows housed in the CCD barn and CBP barn. Lobeck et al. (2011) noted that hock lesion prevalence and lameness prevalence were significantly high in freestalls (23.9%, *P* < .001 and 15.9, *P* < .01 respectively) than in compost bedded pack barns (3.8% and 4.4% respectively). Lobeck et al. (2011) speculated that lameness was lower in the CBP barns compared with freestalls, because cows in CBP barns spend less time standing on concrete.

Compared with the previous studies (Lobeck et al. (2011), cows housed in both the CBP and CCD barns had access to pasture under the semi-grazing system (11 weeks). Hernandez-Mendo (2007) assessed the effect of access to pasture on lameness in cows and demonstrated that even with a short period of access to pasture (over 4 weeks), cows showed improvement in gait
compared with cows kept in confinement. The average prevalence of lameness in the compost dairy barn (0.69 ± 0.01%) was much lower than 7.8% (Barberg et al., 2007a), 9.1% (Shane et al., 2010b), 11.9% (Black, 2013), and 39.24% (Eckelkamp, 2014) lameness in CBP barns. The average lameness prevalence for the CCD barn under semi-grazing system (0.1%) was lower than 2.7% recently reported in cows housed in CCD barns under zero-grazing systems (systems in which cows are kept indoors without outdoor access) in Malawi (Tebug, 2012). Results on the prevalence of lameness (0.69% and 0.04% for CCD and CBP, respectively) and hock lesions (0.00% and 0.00%, for the CCD and CBP, respectively) in the current study suggest that cows in both the CCD and CBP exhibited a high standard of well-being (hock and hoof health).

The average milk yield of cows housed in the CBP (10.89 ± 0.40 kg/day per cow, Table 2.1) was consistent with milk yield in other studies (11 to 15 kg/day) (Banda, 2014). Similar to other studies (Tebug, 2012), milk yield between grazing and semi-grazing systems did not differ in the CCD barn. The mean milk yield of cows housed in CBP was greater compared with milk yield of cows housed in the CBP barns (P < 0.05). However, caution should be exercised when applying these results as changes in management that usually occur with shifting to a new facility (Barberg et al., 2007a, Black, 2013) could have contributed to the observed increase in milk yield.

Milk yield increase of 1.16 kg/day per cow during the dry season for cows housed in the CBP barn was similar to 1.4 kg/day milk yield increase for cows from before to after shifting to the CBP barn (Black, 2013). Black (2013) suggested that the change in animal performance, after moving into a new housing facility, would most likely occur over time because of the gradual increase in dry matter intake. This modest increase in milk production (1.16 kg/day per cow) for the cows housed in the CBP barn could be more important for this low producing herd (11.68 ± 3.9 kg/day).
Conclusion

Semi-grazing systems appear to have no adverse effects on milk yield, SCC, hygiene, sub-clinical high SCC prevalence, lameness, and hock lesion prevalence. Average somatic cell count for the CCD barn during the rainy season was lower under semi-grazing than under grazing system. Because mastitis can cause economic losses to the producer, expenditure on feeding management (cut-and-carry) under a semi-grazing system can be offset by improved udder health.

Average somatic cell count for the CCD barn was > 1,000,000 cells/mL which may indicate possible infection with major pathogens. Cows in the CCD barn appear to face the risk of increased mastitis and hygiene scores during the rainy season. Producers using the CCD barn can counteract these adverse effects by providing adequate stall grooming which has been shown to improve cow hygiene and udder health. Using the CBP barn during the rainy season or using a CBP under a grazing system could be an option.

Because other studies have shown the effect of CCD housing quality on cow hygiene and mastitis during the rainy season (Tebug, 2014; Kawonga et al., 2014), the present needs in CCD barns could be explored further. Lameness (0.69% and 0.04% for the CCD and CBP, respectively) and hock lesion prevalence (0.00% and 0.00%, for the CCD and CBP, respectively) were low, indicating excellent hock and hoof health. Cows in the CBP barn were cleaner, produced more milk, exhibited low SCC, and low sub-clinical high SCC prevalence compared with cows in the CCD barn. Focus on reducing SCC in preventing mastitis infection will be critical in implementing the compost bedded dairy barn as an alternative housing option in Malawi.
Acknowledgment

This material is based upon work supported by the United States Agency for International Development, as part of the Feed the Future initiative, under the CGIAR Fund, award number BFS-G-11-00002, and the predecessor fund the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013. The authors thank all the staff and management at Katete farm, Laboratory staff at Central Veterinary Laboratory in Lilongwe, staff at the Lilongwe University of Agriculture and Natural Resources, staff at the University of Kentucky, Department of Animal and Food sciences for their help during the study.
Table 2.1: Least square means (± SE) from the mixed model analysis showing the effect of housing system on hygiene scores, somatic cell count, sub-clinical high SCC, lameness, and milk yield

<table>
<thead>
<tr>
<th>Measurement</th>
<th>CCD barn</th>
<th>CBP barn</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Hygiene scores</td>
<td>1.80</td>
<td>1.52</td>
<td>0.05</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>2SCC (x10^3 cells/mL)</td>
<td>1045.16</td>
<td>540.16</td>
<td>76.84</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>3Sub-clinical high SCC (%)</td>
<td>65.73</td>
<td>51.36</td>
<td>0.03</td>
<td>0.002</td>
</tr>
<tr>
<td>Milk yield (kg/d per cow)</td>
<td>9.69</td>
<td>10.9</td>
<td>0.57</td>
<td>0.04</td>
</tr>
<tr>
<td>4Lameness (%)</td>
<td>0.69</td>
<td>0.04</td>
<td>0.01</td>
<td>0.49</td>
</tr>
</tbody>
</table>

1Cow hygiene was evaluated weekly by the same observer using a 1 to 4 hygiene scoring system (1 = clean, 4 = dirty)

2Somatic cell counts were analyzed weekly. Cow milk SCC was log transformed to obtain a linear score using the following equation; SCC = Log2 (SCC/100000) +3).

3Sub-clinical high SCC prevalence was calculated as the number of cows with a test SCC >200,000 cells/mL divided by the total cows each week

4Cows were evaluated weekly for lameness using a 1-3 locomotion scoring system (1 = sound: 3 = severely lame) by the same observer at the exit of the milking parlor while cows walked on a flat surface. Lameness prevalence was calculated by dividing the number of cows with a locomotion score of 3 by the total number of cows scored each week (Barberg et al., 2007a).

CCD = Conventional cubicle dairy barn; CBP = Compost bedded pack barn
Table 2.2: Least square means (± SE) from the mixed model analysis showing the effect of housing system on hygiene scores, somatic cell count, sub-clinical high SCC, lameness, and milk yield with cows managed under semi-grazing system during the rainy and dry seasons.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>CCD barn</th>
<th>CBP barn</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rainy season</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hygiene scores</td>
<td>1.96</td>
<td>1.57</td>
<td>0.11</td>
<td>0.002</td>
</tr>
<tr>
<td>SCC (x10$^3$ cells/mL)</td>
<td>855.75</td>
<td>476.22</td>
<td>166.26</td>
<td>0.09</td>
</tr>
<tr>
<td>Sub-clinical high SCC (%)</td>
<td>67</td>
<td>52</td>
<td>0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>Milk yield (kg/d)</td>
<td>9.48</td>
<td>10.06</td>
<td>0.14</td>
<td>0.39</td>
</tr>
<tr>
<td>Lameness (%)</td>
<td>0.11</td>
<td>0.34</td>
<td>0.01</td>
<td>0.98</td>
</tr>
<tr>
<td><strong>Dry season</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hygiene scores</td>
<td>1.65</td>
<td>1.50</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>SCC (x10$^3$ cells/mL)</td>
<td>1016.90</td>
<td>615.78</td>
<td>137.86</td>
<td>0.002</td>
</tr>
<tr>
<td>Sub-clinical high SCC (%)</td>
<td>64</td>
<td>56</td>
<td>0.02</td>
<td>0.45</td>
</tr>
<tr>
<td>Milk yield (kg/d per cow)</td>
<td>9.81</td>
<td>11.22</td>
<td>0.61</td>
<td>0.003</td>
</tr>
<tr>
<td>Lameness (%)</td>
<td>0.56</td>
<td>0.01</td>
<td>0.01</td>
<td>0.45</td>
</tr>
</tbody>
</table>

1Cow hygiene was evaluated weekly by the same observer using a 1 to 4 hygiene scoring system (1= clean, 4 = dirty)

2Somatic cell counts were analyzed weekly. Cow milk SCC was log transformed to obtain a linear score using the following equation; SCC = Log$_2$ (SCC/100000) + 3).

3Sub-clinical high SCC prevalence was calculated as the number of cows with a test SCC >200,000 cells/mL divided by the total cows evaluated each week.
Table 2.2 Cont.

4Cows were evaluated weekly for lameness using a 1-3 locomotion scoring system (1= sound; 3 = severely lame) by the same observer at the exit of the milking parlor while cows walked on a flat surface. Lameness prevalence was calculated by dividing the number of cows with a locomotion score of 3 by the total number of cows scored each week (Barberg et al., 2007a). CCD = Conventional cubicle dairy barn; CBP = Compost bedded pack barn
Table 2.3: Least square means (± SE) from the mixed model analysis showing the effect of management system on hygiene scores, somatic cell count, sub-clinical high SCC, lameness, and milk yield for conventional cubicle-housed cows

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Management system</th>
<th></th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grazing</td>
<td>Semi-grazing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainy season</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hygiene scores</td>
<td>1.96</td>
<td>1.97</td>
<td>0.10</td>
<td>0.91</td>
</tr>
<tr>
<td>SCC (x10³ cells/mL)</td>
<td>1143.19</td>
<td>855.75</td>
<td>131.75</td>
<td>0.03</td>
</tr>
<tr>
<td>Sub-clinical high SCC (%)</td>
<td>68</td>
<td>63</td>
<td>0.08</td>
<td>0.47</td>
</tr>
<tr>
<td>Milk yield (kg/d)</td>
<td>9.09</td>
<td>9.48</td>
<td>0.62</td>
<td>0.14</td>
</tr>
<tr>
<td>Lameness (%)</td>
<td>1.94</td>
<td>0.11</td>
<td>0.01</td>
<td>0.11</td>
</tr>
<tr>
<td>Dry season</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hygiene scores</td>
<td>1.96</td>
<td>1.65</td>
<td>0.10</td>
<td>0.004</td>
</tr>
<tr>
<td>SCC (x10³ cells/mL)</td>
<td>1025.74</td>
<td>1016.90</td>
<td>114.97</td>
<td>0.14</td>
</tr>
<tr>
<td>Sub-clinical high SCC (%)</td>
<td>67</td>
<td>64</td>
<td>0.07</td>
<td>0.57</td>
</tr>
<tr>
<td>Milk yield (kg/d)</td>
<td>10.37</td>
<td>9.81</td>
<td>0.52</td>
<td>0.07</td>
</tr>
<tr>
<td>Lameness (%)</td>
<td>0.16</td>
<td>0.56</td>
<td>0.01</td>
<td>0.95</td>
</tr>
</tbody>
</table>

1Grazing system (systems in which cows are kept at pasture for a large proportion of the day; 33 to 41% of the day) and semi-grazing system (systems in which cows are kept indoors with (16.7% of the day) or without outdoor access).

2Cow hygiene was evaluated weekly by the same observer using a 1 to 4 hygiene scoring system (1 = clean, 4 = dirty).

3Somatic cell counts were analyzed weekly. Cow milk SCC was log transformed to obtain a linear score using the following equation; SCC = Log₂ (SCC/100000) + 3).
Table 2.3 Cont.

4Sub-clinical high SCC prevalence was calculated as the number of cows with a test SCC >200,000 cells/mL divided by the total cows each week

5Cows were evaluated weekly for lameness using a 1-3 locomotion scoring system (1= sound; 3 = severely lame) by the same observer at the exit of the milking parlor while cows walked on a flat surface. Lameness prevalence was calculated by dividing the number of cows with a locomotion score of 3 by the total number of cows scored each week (Barberg et al., 2007a).
Table 2.4. Bacteria isolated from composite milk samples of Holstein-Friesian lactating dairy cows during the rainy and dry seasons on a commercial farm

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Rainy season</th>
<th>Dry season</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequency</td>
<td>Percentage</td>
</tr>
<tr>
<td><em>Streptococcus agalatiae</em></td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td><em>Streptococcus dysgalactiae</em></td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Klebsiella species</td>
<td>27</td>
<td>54</td>
</tr>
<tr>
<td>No growth</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

1 Rainy season (March to April 2017) and Dry season (May to August 2017)

2 Bacteria were isolated from composite milk samples of Holstein-Friesian lactating cows with SCC > 200,000 cells per mL or with clinical mastitis (defined as cows with visual signs of inflammation including swollen udder, redness or heat, abnormal milk, and/or presence of clots in milk)
Figure 2.1. Conventional dairy cattle shed layout with feed manger, stalls, and exercise area
Figure 2. Compost-bedded pack barn layout with bedded pack, walkways, waterer, and feed alley
Figure 2.3. Weekly somatic cell counts in milk samples of loose-housed dairy cows during the rainy and dry seasons. CCD = conventional cubicle dairy barn; CBP = Compost bedded pack barn.
Figure 2.4. Weekly milk production of loose-housed dairy cows during the rainy and dry seasons. CCD = conventional cubicle dairy barn; CBP = Compost bedded pack barn
Chapter Three: Compost bedded pack barn performance in a pasture-based system on a commercial farm in Malawi: A descriptive study

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Abstract

This study evaluated the performance of a compost bedded pack barn (CBP) in a pasture-based system with cows having access to pasture under grazing (systems in which cows are kept at pasture for a large proportion of the day; 33.33\% to 41.67\% of day) or semi-grazing (systems in which cows are kept indoors with (16.67\% of the day) or without access to pasture) systems on a commercial farm in Malawi. Four treatments were sequentially applied on the CBP; Period 1 = rainy season grazing (wk 1 and 3), Period 2 = rainy season semi-grazing (wk 7 and 9), Period 3 = dry season grazing (wk 13, 15, and 17), and period 4 = dry season semi-grazing (wk 21 and 23). Compost bed samples for moisture (\%), pH, carbon, and nitrogen determination were collected twice/month from nine equally divided areas on the pack at 10 cm depth. Bed temperature was measured weekly at the center of the nine areas at 20 cm depth using a probe. Ambient temperature was recorded during the rainy and dry seasons (March 1 to August 2017).
The average (± SD), minimum, and maximum bed temperatures were 30.89 ± 7.5°C, 29°C, and 43.3°C, respectively. Maximum bed temperature (43.3°C) was achieved with the semi-grazing system. No difference between grazing and semi-grazing on compost bed temperature was observed during the rainy season (26.1 ± 7.6 and 31.5 ± 7.8, respectively) or dry season (26.20 ± 8.5 and 36.81 ± 7.7). Mean bed moisture was greater during the rainy season compared with the dry season (48.00 ± 4.87 vs 36.06 ± 7.5%, respectively). No difference between grazing and semi-grazing system on compost pH was observed during the rainy season or dry season (8.25 ± 1.1 vs 8.90 ± 1.2 and 9.78 ± 1.1 vs 9.10 ± 0.66, respectively). No difference between grazing and semi-grazing system on mean C: N ratio was observed (24.27 ± 12.7: 1 and 26.09 ± 13.7: 1, respectively). These results indicate that the performance of the compost bed under the grazing system was comparable to that of the compost bed under the semi-grazing system.

Key words: Compost bedded pack barn, grazing, semi-grazing, composting

Introduction

A compost bedded pack barn is a loose housing system with an open bedded lying area, walkways, and feed alley. In compost bedded pack (CBP) barns, organic bedding is used to create a comfortable lying surface for the cows. The bedded pack is stirred twice daily to incorporate urine and feces in the pack and to create a clean dry resting surface for the cows. The optimal pack density (cow resting surface per m²) for Holstein dairy cows measures 10 m². The large lying surface allows cows to lie down more naturally in the bedded pack. Composting is a biological process where microorganisms (mostly bacteria and fungi) decompose organic matter in aerobic conditions. During aerobic decomposition, microorganisms breakdown organic matter into moisture, heat, and carbon dioxide (NRAES, 1992). Carbon released from the microbial breakdown of organic matter provides energy for microbial growth. Nitrogen is utilized by microorganisms for
protein synthesis and reproduction. Moisture provides the medium for biological activities. For aerobic decomposition, the optimal moisture range is 40 to 60%. Microbial biological activities are affected at moisture content above 65% and cease at moisture content below 15% (NRAES, 1992). With high moisture content (> 60%), most of the pore spaces within the bed are filled with water, reducing the rate of supply of oxygen to microorganisms in the bed.

When oxygen is insufficient in supply, intermediate compounds such as methane, hydrogen sulfide and organic acids are released (NRAES, 1992). Also, moisture is a principal factor affecting temperature changes because of its high specific heat capacity compared to other materials. The thermal conductivity and latent heat properties of water are important in the evaporation of moisture from the bed.

Temperature and moisture are crucial factors determining the success of composting process (NRAES, 1992). Heat generated by microbial activities raises the compost bed temperature. However, the overall compost bed temperature depends on how much heat is being produced by the microorganisms which is balanced by the heat loss through aeration or surface cooling through conduction and evaporation (NRAES, 1992). Imbalances between heat generation and loss can cool the pack.

The optimal compost bed temperature is between 43.3 to 65 °C (15-31 cm depth at bottom of tillage layer) (Janni et al., 2006). Benefits of targeting greater compost bed temperatures (43 to 65 °C) include reduced bedding costs and a dry resting surface for cows due to increased moisture loss by evaporation. Because a CBP barn is a semi-composting system (Russelle et al., 2009), attaining optimal composting temperatures can be difficult.

Results of six studies (Galama, 2009, Shane et al., 2010b, Klaas and Bjerg, 2012, Black et al., 2013, Leso et al., 2013, Eckelkamp, 2014) indicated an average bed temperature of 20 to 58°C. However, higher temperatures (44 to 55°C) are required for efficient decomposition.
Maintaining a proper balance of carbon to nitrogen is important for greater microbial breakdown of organic materials (NRAES, 1992). The optimal carbon to nitrogen ratio is within the range of 25:1 to 30:1 (NRAES 54, 1992). If the C:N ratio is < 25:1, all available carbon is used without stabilizing all nitrogen (NRAES, 1992). This excess nitrogen is lost as ammonia. If the C:N ratio is > 30:1, the rate of decomposition decreases (NRAES, 1992). The optimal pH is 6.5 to 8.0. High compost pH (>8.5) promotes ammonia loss because nitrogenous compounds are converted to ammonia at a high bed pH. Production of organic acids during initial stages of composting lowers the compost pH. Ammonia production raises the pH of the composting material. However, the composting process stabilizes bed pH. Thus, properly composted materials have a pH close to neutral (NRAES, 1992).

The bed in CBP barns is influenced by many factors, including bedding type, bedding addition, weather, tillage strategy, barn structure, precipitation, and barn ventilation (Damasceno, 2012, Black, 2013). Stirring the pack to 20 cm depth creates a fluffy bed (Lobeck et al., 2011), allows air to mix and infiltrate into the pack, and enhances microbial breakdown of the organic materials with higher oxygen content.

Precipitation and water spillage in the pack can increase bed moisture content (NRAES, 1992, Bewley et al., 2013). Weather conditions can influence compost bed moisture content. For example, low air temperature in the winter can lead to high bed moisture content (>60%) due to reduced drying rate (Black, 2013). High air temperature in the summer can result in drier compost due to increased drying rate. Drier compost tends to heat up and cool off quickly, causing changes in compost bed temperature. Thus, maintaining bed moisture content within the optimal range of 40 to 60% is important. Visually, a well composting bed is loose and fluffy (Barberg et al., 2007).

The association between pasture access, compost bed temperature, and moisture content has been previously studied (Black, 2013). However, compost bedded pack housing is a newer
housing concept (Janni et al., 2007) and most of the practical aspects of the CBP barn are not clear (Klaas and Bjerg, 2012, Galama et al., 2015). Additionally, few studies on the performance of compost bedded pack housing systems with a grazing system or semi-grazing system exists. The objective of this study was to describe the performance of the compost bed with cows managed under grazing or semi-grazing system during the rainy and dry season in a sub-tropical environment in Malawi.

**Materials and Methods**

**Study design**

A single-system study was designed to describe the performance of the compost bed (compost bed temperature, moisture content, pH, and carbon to nitrogen ratio) with cows managed under a grazing system (in which cows are allowed access to pasture for a greater proportion of day; 33.33 to 41.67% of the day) and a semi-grazing system (in which cows are kept indoors with (16.67% of the day) or without outdoor access) in one commercial dairy herd in Lilongwe, Malawi (Southeast Africa, Figure 3.1). Four treatments were sequentially applied on the CBP; Period 1 = rainy season grazing (wk 1 to 4; grazing), Period 2 = rainy season semi-grazing (wk 6 to 9; semi-grazing), Period 3 = dry season grazing (wk 11 to 16; grazing), and period 4 = dry season semi-grazing (wk 18 to 23). This study was conducted during the rainy and dry season (March 1 to August 30, 2017).

**Compost Bedded Pack Housing System**

**Barn Structure**

The compost bedded pack barn (Figure 3.2) was designed with east-west orientation (89.96°). The east-west orientation is important because it increases the shaded area for the cows. The CBP barn used natural ventilation. The side walls and eave overhang were 4 m high and 1 m long, respectively. The eaves are required to prevent rainfall from entering the pack. An open
ridge with a cover was used to promote air ventilation in the barn. A wire mesh to prevent birds from entering the barn was used along the long side of the ridge vent. The compost bedded pack barn provided 9.71 m² of lying space per cow. The CBP barn was constructed with a clay base. The bedded pack was surrounded by a 1.2 m wall (wooden planks) on all sides and a 1.2 m high wall separating the pack and a feed alley. The concrete feed alley was located on one long side of the barn. Two access points were located along the long side of the bedded pack. Waterers were located in the feed alley.

Pack Management

The compost bedded pack was stirred twice a day (15.6 cm deep) using a cultivator to provide a dry laying surface when cows were at milking. The CBP barn sawdust bedding (dry sawdust from soft wood of pines and hard wood) depth at the beginning of the study was 50.2 cm. Bedding (10 cm) was added to the bedded pack based on moisture guideline (40 to 60%) for compost bedded pack barns. Bedding was added to the pack more frequently in the rainy season (3 to 6 weeks) than in the dry season (6 to 8.5 weeks). The concrete floor in the compost bedded pack feed alley was scraped at 0800 h daily using a hand-held scraper and broom. The study personnel evaluated the management of the bedded pack to ensure that the pack was managed identically when cows were under grazing or semi-grazing systems.

Management of Animals housed in compost bedded pack barn

Thirty-five multiparous Holstein-Friesian cows (mean weekly milk production = 10.89 ± 3.8 kg/day) were housed in the compost bedded pack housing for 24 weeks (March to August 2017). All cows were milked twice a day (0200 h and 1400 h) in a 2 x 12 milking parlor. Cows were managed under a grazing system (in which cows are allowed access to pasture for 33.33 to 41% of day) and a semi-grazing system (in which cows are kept indoors with outdoor access (16.67% of the day) or without outdoor access). Forages were supplemented with a concentrate formulated using soy bean meal, sunflower cake, maize bran, and Vitamin premix as described
by (Chizonda, 2015). The concentrate was fed separately in the parlor during milking. Each cow was individually fed 4 kg concentrate at each milking (0200 h and 1400 h). All cows were provided Napier grass (*pennisetum purpureum*) mixed with maize bran and molasses under the semi-grazing system. Waterers were located in the alley side in the CBP barn.

**Data Collection**

Malawi is dominated by a sub-humid tropical climate, with two distinct weather conditions: the rainy season (November to April) and the dry season (May to October). This study was conducted during the rainy and dry seasons (March 1 to August 30 2017).

**Bedded Pack Characteristics**

**Compost Sample Collection**

The compost bedded pack was divided into nine equal points (A1 to A9, Figure 3.3). Each data collection point was a 3 x 3 m rectangular area that divided the pack into nine equal areas (Black, 2013). Compost samples for measurement of pH, moisture, total carbon, and total nitrogen were collected from the center of the nine points using a hoe.

Compost samples were collected twice/month at nine equally divided areas on the pack, mixed in a 5 liter bucket, sub-sampled to form a composite sample (0.75 to 1 kg), stored in a cooler with ice parks, and transported to Lilongwe University of Agriculture and Natural Resources (LUANAR) Soil Science Laboratory for further analysis. Samples were frozen if not used within 24 hours.

**Compost Bed Temperature**

Compost bed temperature is a good indicator of composting success. Optimal composting occurs at a temperature range of 43 to 60 °C (NRAES, 1992). Compost bed temperature was measured weekly at the center of the nine equally divided areas (Figure 3.3) at 20 cm depth using K-Type Thermocouple Probe with a measurement range of -40 °C to 260 °C (accuracy
of ± 2.2 °C; Fluke®, model 62, Everett, WA, USA). The thermocouple probe was inserted at 20 cm depth, left to stabilize before recording bed temperature (°C).

**Compost Bed Moisture Content**

Compost moisture content was determined using the oven drying method (Lester et al., 2007; ASABE, 2009). Samples of approximately 10 g were dried at 103 °C for 24 hours in a drying oven, placed in a desiccator to cool at room temperature and weighed (gross weight of container with oven dried sample). Oven dried weight was determined by subtracting weight of the container from gross weight. Moisture content (%) was calculated using equation 1.0:

\[
MC_{\text{wet-basis}} = \left[ \frac{w_w - d_w}{W_w} \right] \times 100
\]

Eq. 1.0

Where \(MC_{\text{wet-basis}}\) is the moisture content as a percentage, \(w_w\) is the weight of wet material (g), and \(d_w\) is the dry weight (g) of material determined by drying sample in a drying oven at 103°C for 24 h.

**Compost pH**

Bedding samples were collected twice/mo from the nine equally divided areas on the pack for pH determination. Compost sample pH was analyzed by adding 10g of sample (as-is) into 25 mL of deionized water. The mixture was left to stand for 30 minutes with occasional mixing using a mechanical shaker. Compost pH was measured with a calibrated (pH 7 and 10 buffers) electrode. The electrode (Oakton Instruments®, Vernon Hills, IL, USA) was calibrated by placing it in a pH 7 buffer until the reading stabilized.

The electrode was set to 7, rinsed with deionized water, dried, and was placed in pH 10 buffer until the reading stabilized. Compost pH was measured by placing the electrode in the sample flask with the compost sample (10 g) submerged in 25 ml of deionized water for 30 minutes and recording the pH.
Compost Carbon and Nitrogen

Compost samples for carbon (%) and nitrogen (%) determination were collected twice/mo. Samples were analyzed in triplicate for total carbon and total nitrogen.

Carbon determination

Total carbon was determined by Walkley-Black wet oxidation Method, which is a wet oxidation of organic carbon by acidified dichromate. A sub-sample (1g) was dried (50°C) and ground (2 mm sieve) before carbon determination. The oven dried sample (1 g) was mixed with 10 ml 1N potassium dichromate (K₂Cr₂O₇). The mixture was acidified by mixing 100ml of distilled water and 10ml of concentrated sulphuric acid. Diphenylamine indicator (1ml) was added, and titrated with 0.5N ammonium ferrous sulphate. A blank sample (B) was included. Percent carbon was calculated using the following formula;

\[
\% \text{ carbon} = \frac{B - S}{x} 
\times 0.5 \times 0.003 \times 100 \times 1.3
\]

Where \% carbon is the calculated carbon in percentage, B is the black sample, and S is the sample.

Nitrogen analysis

Nitrogen content in compost was determined using a spectrophotometer. Standards were prepared by adding 0, 2.00, 4.00, 6.00, and 8.00 ml of 100 ppm N stock solution in 100ml digestion tubes. The volume was then made to 50 ml by adding distilled water. The final solutions contained 0, 4.00, 8.00, 12.00, and 16.00 ppm N, respectively. Compost samples were weighed (0.200g), ground, and mixed into a 50 ml digestion tube. Digestion solution (4.4 ml) was added to each tube. Samples were digested on a hot plate for 2 hours at 360°C, and cooled. The samples were diluted to 50 ml. 5 ml of N1 (sodium citrate, sodium salicylate, sodium tetrathionate, sodium nitroprusside, and deionized water) was added to samples (0.500ml) and standards (0.500ml) in 20ml glass vials and left to stand for 1 h for full color development. The compost samples and the standards were read at 655 nm on a UV-Vis spectrophotometer.
standard curve was drawn and concentrations (mg/L) of samples were obtained by substituting the absorbance of samples in equation from the standard curve.

**Carbon to nitrogen ratio**

Carbon to nitrogen ratio was calculated as carbon content divided by nitrogen content. Carbon to nitrogen ratio was calculated for each sample on dry weight basis.

**Climatic conditions**

Climatic data for the study farm was collected from the Meteological Department database in Malawi. Air temperature and relative humidity data from March 1 to August 30, 2017 were recorded using weather station at Chitedze Research Station located in Lilongwe (Figure 3.1). Temperature-humidity values were calculated based on the average temperature and humidity data obtained from the weather stations and defined by the following equation (Ravagnolo and Misztal, 2000): $\text{THI} = [(1.8 \times T) + 32] - (0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)$, where $T$ is the dry bulb temperature in degrees Celsius, and RH is the relative humidity in percentage.

**Barn environment**

Temperature and relative humidity were measured and recorded by temperature and humidity sensors (Hobo U23 pro V2, Onset Computer Corp., Bourne, MA). Temperature humidity index was calculated using the following equation defined by Ravagnolo and Misztal, (2000): $\text{THI} = [(1.8 \times T) + 32] - (0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)$, where $T$ is the dry bulb temperature in degrees Celsius, and RH is the relative humidity in percentage.

**Statistical Analysis**

Descriptive statistics using MEANS procedure of SAS (SAS Institute Inc., Cary, NC) were used to describe the average compost bed temperature, moisture content, pH, carbon to nitrogen ratio, outside air temperature, compost bedded dairy barn temperature, humidity, and temperature humidity index.
PROC GLM of SAS (version 9.3, SAS Institute Inc., Cary, NC) was used to compare compost bed temperature, compost bed moisture, compost pH, and compost C:N in the compost bedded dairy barn with cows managed under grazing or semi-grazing systems (Period 1 = rainy season grazing (wk 1 to 4; grazing), Period 2 = rainy season semi-grazing (wk 6 to 9; semi-grazing), Period 3 = dry season grazing (wk 11 to 16; grazing), and Period 4 = dry season semi-grazing (wk 18 to 23). LSMEANS option in SAS (version 9.3, SAS Institute Inc., Cary, NC) was used to test differences between means. Significance was declared at \( P < 0.05 \). Data were checked for normality of variance by visual plots. Analysis of outliers was performed using box plots.

**Results and Discussion**

**Climatic conditions and barn environment**

The characteristics of the CBP barn environment are presented in Table 3.1. Temperature, relative humidity, and temperature humidity index (THI) trends for the CBP barn are described in Figure 3.4. Average (± SD) barn temperature (°C), humidity (%), and temperature-humidity index were 20.34 ± 1.79, 70.98 ± 8.23, and 67.01 ± 3.06, respectively (Table 3.1). The average (± SD) THI inside the CBP barn was 67 ± 3.06 (Table 3.1). Temperature-humidity Index during the rainy season ranged from 66 to 72 and 60 to 66 during the dry season (data not shown). Management system by season interaction on THI was not detected (\( P > 0.05 \)). The mean, minimum, and maximum outside air temperature, compost bed temperature, and compost moisture content are presented in Table 3.2. The average, minimum, and maximum bed temperatures at 20 cm depth were 31 ± 7.5°C, 24°C, and 43°C, respectively. The average, minimum, and maximum bed moisture content were 41.81 ± 8.0%, 28.57% and 53.62%, respectively. The average (± SD), minimum, and maximum outside air temperature were 19.47 ± 4.98°C, 14.88°C, and 26.0°C, respectively.
**Compost Bed Characteristics**

**Compost Bed Temperature**

Results for average compost bed temperature for the CBP barn with cows managed under grazing or semi-grazing systems during the rainy and dry seasons are presented in Table 3.3. Figure 3.6 show the trend in compost bed temperature during the 6 mo study (24 wk). The mean compost bed temperature was 30.89 ± 7.5 with a range of 24 to 43.3°C (Table 3.2). Black et al. (2013) also reported lower mean bed temperature (36.1 ± 11.0°C) across 47 CBP barns in Kentucky which covered warm-cold seasons. The compost temperature range of 24 to 43.3°C in the current study was comparable to 24.2 to 33.4°C across 8 Italian CBP barns (Leso et al., 2013), 20 to 40°C across 7 CBP barns in Israel (Klaas and Bjerg, 2012), and 31.8 to 48.1°C and 13.8 to 40.6°C in summer and winter, respectively, across 6 Minnesota CBP barns (Shane et al., 2010b). Barberg et al. (2007) reported greater mean bed temperature of 42.5°C in CBP barns.

In general, the average compost bed temperature (30.89 ± 7.5°C) shown in Table 3.2 was below the optimal range of 43.3 to 65.0°C (NRAES, 1992) for efficient composting. No management system by season interaction on compost bed temperature was detected (P > 0.05). Mean (± se) compost bed temperature did not differ between grazing and semi-grazing during the rainy season (26.09 ± 0.20°C and 31.50 ± 0.45°C, respectively, P > 0.05, Table 3.3, Figure 3.5). Compost bed temperature did not differ between grazing and semi-grazing systems during the dry season (26.20 ± 0.60°C and 36.81 ± 0.60°C, respectively, P > 0.05, Table 3.3).

The results in Figure 3.6 indicate a gradual increase in compost bed temperature with maximum bed temperature (43.3°C) observed in week 23 under semi-grazing system. These results suggest that for the Malawian sub-tropical climate, combining a CBP barn with a grazing or semi-grazing system may result in longer composting times to achieve optimal composting temperatures (43 to 60°C) (NRAES, 1992). However, CBP barns are often managed for dry
resting surfaces rather than greater bed temperature (Janni et al., 2007, Black, 2013). Bed moisture content at the maximum bed temperature (43.3 °C, Figure 3.9) was 42.61 percent. (Black et al., 2013) also found greater bed temperature (up to 57.77 °C) in the moisture range of 45 to 55 percent.

**Compost Bed Moisture**

Table 3.4 shows the average bed moisture for the CBP barn during grazing or semi-grazing. Figure 3.7 shows the average compost bed moisture content (%) during the rainy and dry seasons. Figure 3.8 shows the trend in air temperature (°C) during rainy and dry seasons. Results of compost bed moisture and compost bed temperature trends are presented in Figure 3.9. Results of compost bed temperature and outside temperature trends are presented in Figure 3.10.

Average (± se) compost bed moisture content did not differ between grazing and semi-grazing systems during the rainy season (44.89 ± 0.9% and 38.65 ± 0.92%, respectively, \( P > 0.05 \)). However, the average (± se) compost bed moisture content was greater under semi-grazing compared with grazing system during the dry season (52.10 ± 0.7% and 33.46 ± 0.9%, respectively, \( P < 0.05 \)). The results in Table 3.4 indicate that bed moisture content was more consistent for the grazing system for the rainy and dry season, (44.89 ± 0.9% and 38.65 ± 0.92%, respectively, \( P > 0.05 \)) compared with the semi-grazing period for the rainy and dry season (52.10 ± 0.7% and 33.46 ± 0.9%, respectively, \( P < 0.05 \)).

Results for outside air temperature presented in Figure 3.8 indicate that outside air temperature was greater during the rainy season compared with the dry season (21.40 ± 3.19°C vs 16.78 ± 1.93°C, respectively, \( P < 0.05 \)). Seasonally, compost bed moisture content was numerically greater during the rainy season compared with the dry season (48.00 ± 4.87% vs 40.89 ± 6.71%, respectively, \( P = 0.09 \), Figure 3.7). This difference in compost bed moisture content between the rainy and the dry seasons could be explained by the greater air temperature (21.40 ± 3.19...
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vs 16.78 ± 1.93, respectively, \( P < 0.05 \), Figure 3.8) and relative humidity (Figure 3.9) during the rainy season compared with the dry season which might have resulted in humid conditions leading to slower drying rate (Black et al., 2013). Average (± se) compost bed moisture content (41.81 ± 8, Table 3.2) in the current study was within the optimal moisture content range for composting (40 to 60%) (NRAES, 1992) and for compost bedded pack barns—28 to 78.9% (Barberg et al., 2007) and 30 to 40% (Galama, 2009).

However, the average moisture content (41.81 ± 8) was lower than 56.1 ± 12.4% in 47 Kentucky CBP barns (Black et al., 2013), 59.9 ± 6.6, in 8 Kentucky CBP barns (Eckelkamp, 2014), and 56.7 ± 8.8% in 12 Minnesota CBP barns (Barberg et al., 2007a). This low mean bed moisture content (41.81 ± 8) in the current CBP barn compared with CBP bed moisture content observed in the studies of Black et al. (2014) and Eckelkamp (2014) could be due to the differences in management systems employed. Cows in the current study were managed under a grazing system or a combination of grazing and confinement (semi-grazing). For the previous studies (Black et al., 2013, Eckelkamp, 2014) cows were in confinement. A greater proportion of bed moisture is from urine and feces (Galama, 2009). Thus, grazing or access to pastures can limit this amount because less urine and feces are deposited on the pack (Black, 2013).

**Compost pH and Carbon to Nitrogen Ratio**

Table 3.5 describes the mean, minimum, and maximum compost pH and carbon to nitrogen ratio. Figure 3.11 describes seasonal trends in compost pH and carbon to nitrogen ratio. The mean (± SD), minimum, and maximum compost pH were 9.02 ± 0.59, 8, 10, respectively. Black (2013) reported lower pH (8.2) in CBP compost. However, this pH (9.02 ± 0.84) was similar to pH (8.6) reported by (Russelle et al., 2009) and pH (8.83) in 6 Minnesota compost bedded pack barns (Shane et al., 2010b).
Table 3.6 describes the mean, compost pH for the grazing and semi-grazing system during the rainy and dry seasons. Mean (± se) compost pH did not differ between the grazing and semi-grazing during the rainy season (8.25 ± 0.45 and 8.9 ± 0.90, respectively, \( P > 0.05 \)) and the dry seasons (9.78 ± 0.6 and 9.10 ± 0.60, respectively, \( P > 0.05 \)). The mean compost pH for the grazing and semi-grazing system during the rainy season (8.25 ± 0.45 and 8.9 ± 0.90, respectively, \( P > 0.05 \)) and for dry season (9.78 ± 0.6 and 9.10 ± 0.60, respectively, \( P > 0.05 \)) were outside the optimal pH (6.5 to 8.0) for composting (NRAES, 1992). In CBP bed, maintaining optimal composting pH (6.5 to 8.0) might be more difficult for CBP barn composting conditions because urine and feces, high in organic N (NRAES, 1992) and bedding (high carbon source) are added to the pack continuously (Black, 2013). Thus, the CBP barn works more like a semi-composting system (Russelle et al., 2009).

The mean (± SD), minimum, and maximum compost carbon to nitrogen ratios (C:N) were 25.43 ± 13.17:1, 10:1, and 42:1, respectively (Table 3.5). The mean (± SD) C:N ratio (25.43 ± 13.17:1) was within the optimal C:N ratio for composting (25:1 to 30:1) (NRAES, 1992). (Black et al., 2013) also reported C:N ratio of 26.7 ± 7.8:1 in 47 compost bedded pack barns in Kentucky. However, C:N ratio (24.75 ± 12.79:1) for the CBP barn in the current study was greater than C:N ratio of 17.8:1 (Shane et al., 2010b), C:N ratio of 21.4:1 (Barberg et al., 2007a), and 20.5 ± 5.9:1 (Eckelkamp, 2014) for compost barns. The C:N ratio in the current study ranged from 10:1 to 42:1, indicating a great range in C:N ratio within this housing system. Black (2013) also found a great C:N ratio range of 11.3:1 to 43.2:1. Russelle et al. (2009) found a narrower C:N ratio range of 11.2:1 to 20.9:1. Carbon to nitrogen ratio in CBP barns will most likely depend on specific farm management practices (Black et al., 2013).
As expected, the compost pH was greater at a lower carbon to nitrogen ratio (Figure 3.11) because at lower C:N ratio (< 25:1), all available carbon is used before all nitrogen is stabilized (NRAES, 1992). This excess N in organic material is lost as ammonia, increasing the compost bed pH (NRAES, 1992). No difference between grazing and semi-grazing system for the bed pH during the rainy and dry season was observed (Figure 3.12).

**Conclusion**

The semi-grazing system showed greater average bed moisture content during the rainy season compared with the dry season. No major differences were observed in average compost bed moisture, temperature, pH, and carbon to nitrogen ratio between grazing and semi-grazing system during the rainy and dry seasons. These results could have been powerful with a comparison with confinement system (zero-grazing); however, this was not possible at this pasture-based commercial herd. Compost pH varied with the season. Results from this study suggest that performance of the compost bedded pack during the grazing system was comparable to that of compost bedded pack under the semi-grazing system.

**Acknowledgment**

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Table 3.1. Mean and standard deviation of temperature, relative humidity, and temperature-humidity index in the compost bedded pack barn

<table>
<thead>
<tr>
<th>Climatic condition</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td>20.34</td>
<td>1.79</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>70.98</td>
<td>8.23</td>
</tr>
<tr>
<td>¹Temperature-humidity index</td>
<td>67.01</td>
<td>3.06</td>
</tr>
</tbody>
</table>

¹Temperature humidity index (THI) was calculated using the equation by Ravagnolo and Misztal (2000): THI = [(1.8*T) + 32] – (0.55 – 0.0055*RH) * (1.8 *T – 26), where T is the dry bulb temperature in degrees Celsius, and RH is the relative humidity in percentage

²SD is standard deviation
Table 3.2: Descriptive statistics of compost bed temperature, compost bed moisture content, and outside air temperature

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Outside air temperature (°C)</td>
<td></td>
<td>15</td>
<td>26.0</td>
<td>19.5</td>
<td>3.1</td>
</tr>
<tr>
<td>2Bed temperature (°C)</td>
<td></td>
<td>24</td>
<td>43</td>
<td>31</td>
<td>7.5</td>
</tr>
<tr>
<td>3Bed moisture (%)</td>
<td></td>
<td>29</td>
<td>54.0</td>
<td>41.3</td>
<td>8.3</td>
</tr>
</tbody>
</table>

1Outside air temperature (°C) was recorded by dry bulb thermometer

2Compost bed temperature (°C) was measured at the center of the nine equally divided areas on the bedded pack at 20 cm depth using a probe.

3Compost moisture content was calculated as the wet weight minus dry weight divided by the dry weight minus the container weight. Percent moisture content was calculated as moisture content multiplied by 100.

SD = Standard deviation
Table 3.3. Least square means of compost bed temperature in the compost bedded dairy barn with cows managed under grazing or semi-grazing during the rainy and dry seasons

<table>
<thead>
<tr>
<th>Season</th>
<th>Grazing period</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grazing</td>
<td>Semi-grazing</td>
<td>LSM</td>
<td>SE</td>
<td>LSM</td>
</tr>
<tr>
<td>Rainy season</td>
<td>26.1</td>
<td>0.2</td>
<td>31.5</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Dry season</td>
<td>26.2</td>
<td>0.6</td>
<td>36.8</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>

1 Grazing are systems in which cows are allowed access to pasture for a greater proportion of day; 33.33 to 41% of the day); Semi-grazing are systems in which cows are kept indoors with (16.67% of the day) or without outdoor access

2 The study was conducted during the rainy season (March to April) and dry season (May to August).

LSM = Least square means; SE = Standard error
Table 3.4. Least square means of compost bed moisture content in the compost bedded dairy barn under grazing or semi-grazing during the rainy and dry season

<table>
<thead>
<tr>
<th>Season</th>
<th>Grazing</th>
<th>Semi-grazing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LSM</td>
<td>SE</td>
</tr>
<tr>
<td>Rainy season</td>
<td>44.89&lt;sup&gt;x&lt;/sup&gt;</td>
<td>0.9</td>
</tr>
<tr>
<td>Dry season</td>
<td>38.65&lt;sup&gt;x&lt;/sup&gt;</td>
<td>0.9</td>
</tr>
</tbody>
</table>

<sup>x, y</sup> Means in the same column with different superscript are significantly different (P < 0.05)

<sup>1</sup>Grazing are systems in which cows are allowed access to pasture for a greater proportion of day; 33.33 to 41% of the day; Semi-grazing are systems in which cows are kept indoors with (16.67% of the day) or without outdoor access

<sup>2</sup>The study was conducted during the rainy season (March to April) and dry season (May to August).

LSM = Least square means; SE = Standard error
Table 3. 5. Descriptive statistics for the compost pH and carbon to nitrogen ratio in the compost bedded dairy barn

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pH</td>
<td></td>
<td>8</td>
<td>10</td>
<td>9.02</td>
<td>0.6</td>
</tr>
<tr>
<td>2 Carbon to nitrogen ratio</td>
<td></td>
<td>10</td>
<td>42</td>
<td>25.43</td>
<td>13.1</td>
</tr>
</tbody>
</table>

1 Compost pH was measured by placing electrode in a sample flask with the compost sample (10 g) submerged in 25 ml of deionized water for 30 minutes and recording the pH.

2 Compost carbon to nitrogen ration was calculated as total carbon divided by total nitrogen

SD = Standard deviation
Table 3. 6. Least square means of compost bed pH in the compost bedded dairy barn under grazing or semi-grazing during the rainy and dry season

<table>
<thead>
<tr>
<th>Season</th>
<th>Grazing</th>
<th>Semi-grazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainy season</td>
<td>8.25</td>
<td>9.78</td>
</tr>
<tr>
<td>Dry season</td>
<td>8.90</td>
<td>9.10</td>
</tr>
</tbody>
</table>

1Grazing are systems in which cows are allowed access to pasture for a greater proportion of day; 33.33 to 41% of the day; Semi-grazing are systems in which cows are kept indoors with (16.67% of the day) or without outdoor access

2The study was conducted during the rainy season (March to April) and dry season (May to August).

LSM = Least square means; SE = Standard error
Figure 3.1. Map of Malawi showing rainfall pattern and locations of weather stations.
Figure 3.2. Compost-bedded dairy barn layout with bedded pack, walkways, waterers, and feed alley
Figure 3.3. Sampling location A1 to A9 on the bedded pack
Figure 3.4. Average ambient temperature (°C), relative humidity (%), and temperature-humidity index (THI) by week (March to August)
Figure 3. 5. Compost bed temperature (°C) during the rainy and dry seasons
Figure 3.6. Compost bed temperature trend during the rainy and dry seasons
Figure 3.7. Average compost bed moisture content (%) during the rainy and dry seasons.
Figure 3. 8. Average air temperature (°C) during rainy and dry seasons in Lilongwe Agro-ecological Area. Letters (a, b) denoted significant difference ($P < 0.05$)
Figure 3. 9. Average compost bed moisture and compost bed temperature over 24 weeks
Figure 3. 10. Average compost bed moisture and outside air temperature over 24 weeks
Figure 3. 11. Seasonal compost bed pH and carbon to nitrogen ratio over 24 weeks.

Arrows represent points of sawdust bedding addition
Chapter Four: Investing in compost bedded dairy housing technology: A partial budget approach

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Abstract

The objective of this study was to assess the economic viability of investing in a compost bedded dairy (CBP) housing technology using the partial budget analysis approach. This study was undertaken over a period of six months (March 1 to August 30 2017) through a series of visits to a commercial dairy farm in central Malawi. A partial budget was developed to examine the effect of investing in a CBP barn on net returns. The net returns indicate the amount that could be realized for the CBP housing given the costs and other factors associated with the previous housing such as milk yields, prices, manure value, health cost, and labor cost. Net returns were determined by calculating expected increase and decrease in revenue and in costs. Net returns greater or equal to zero indicate that the decision to invest in a CBP barn is viable; a negative net return indicates that the investment is not viable. Barn cost, feed price, labor, and bedding costs were $473 per cow space, $0.55 per kg DM, $0.13 per hour, and $0.86 per m³, respectively. The average exchange rate (Malawi Kwacha to 1 US dollar) during the 6 mo study was K715 to 1 US $. In the default scenario (CBP combined with grazing and semi-
grazing system), the reduced costs were $1,023. Milk yield increased by 6% during the 6 mo study. With milk price of $0.47/kg, added milk income was $1,959. The net return of investing in a CBP barn during this study was $881 in the default scenario, 19.6% lower than that of the CBP barn with a grazing scenario. Sensitivity analysis showed initial CBP barn costs, milk yield, and milk price to be important variables affecting the net returns. The results of this study suggest that, it was viable to invest in a CBP barn in a grazing system. The benefits of the CBP over CCD are $1425 per year, but it would take an investment of $5368. The farmer would be expected to pay back the investment in 3.77 years.

Keywords: Compost bedded dairy barn, viability, pasture-based system

Introduction

Management systems for dairy cattle vary across the world. Malawian commercial dairy farmers mostly utilize grazing systems (systems in which cows are kept at pasture for a large proportion of the day). However, this practice is changing. Commercial farms are increasingly practicing semi-grazing systems (systems in which cows are kept indoors for a large proportion of the day with or without outdoor access) (Chizonda, 2015). In semi-grazing systems, dairy cattle are housed in cubicle dairy cattle barns (Banda et al., 2012, Kawonga et al., 2012). Apart from providing shelter at night, the housing facilities are important because they protect animals from incremental weather conditions. However, building a new conventional cubicle dairy (CCD) barn requires a high capital investment in hardware or timber for stalls, labor for barn construction, and concrete for the stall base, the feed alley, and the exercise area (Figure 4.1).

Recent estimates of the cost of building a CCD barn range between $625 and $895 per cow space (MBG extension personnel, Ministry of Agriculture, Personal communication). Farmers know that maintaining a CCD barn annually and replacing the shed within 3 to 5 years is
expensive, but they still construct these facilities because they underestimate the costs of building and maintaining the conventional dairy housing (MBG extension personnel, Ministry of Agriculture, Personal communication). Malawian producers do not value family labor and the cost of non-marketed construction materials such as grass for roofing, bricks for perimeter wall, sand, quarry stone, and water for mixing concrete. Adding these costs to the initial CCD barn cost, expenditure would signal a much higher cost. However, farmers who made the investments in the CCD barns, perhaps have more flexibility remodeling these structures if their herd grows.

Although, improving the housing environment can improve labor efficiency and generate more income because of improved management (Black et al., 2014), however, few dairy farmers in Malawi invest in improved housing due to uncertainty of the benefits of investing in housing on overall farm profitability. Benefits of improved housing, including milk production, reproductive performance, lameness, cow hygiene, manure management, udder health, and milk quality vary (Black et al., 2014). These benefits vary due to inefficiencies in housing management such as cow hygiene, bedding management (Banda et al., 2012, Kawonga et al., 2012), and labor.

The CCD barn was designed in the early 1960s to control overgrown hoofs, to minimize tick borne diseases, and to provide shelter from adverse weather conditions. However, several studies (Banda et al., 2012, Kawonga et al., 2012, Tebug, 2012) have provided evidence of poor cow health, fertility, and poor hygiene in CCD barns. These inefficiencies in CCD barn management can reduce the benefits that are associated with providing cows with housing because cows housed in CCD barns have either a high mastitis prevalence (54.6%) (Tebug, 2012) or low lying times (9 hour/d) (Banda, 2014). This low lying time of cows housed in CCD barns has been associated with reduced fertility (Banda, 2014).
Black (2013) evaluated the viability of investing in compost bedded pack (CBP) barns (Figure 4.2) after pasture-based herds’ transition to CBP barns. However, no study has incorporated the variation in the performance and health of cows housed in CBP barns where the CBP housing is combined with a pasture–based system to determine the viability of investing in the CBP barn. In addition, newer housing technologies such as the compost bedded pack barn may not be viable in the sub-tropics because of the great differences in socioeconomic conditions between the two production systems (Anderson and Dillon, 1992, Moran, 2005, Berg, 2013). According to Berg (2013), technologies must be relevant to the needs of the farmers as well as feasible given the environment in which the system operates. Therefore, the development of animal housing systems that take into consideration both the productive benefits of the system and economic factors are needed.

Production costs in zero-grazing herds such as bedding costs have previously been compared with costs in pasture-based herds (Black, 2013). Compared with zero grazing herds, pasture-based herds reported lower bedding costs (Black, 2013). The author (Black, 2013) speculated that bedding costs were lower for grazing herds because less urine and feces were voided on the pack. We hypothesized that combining a CBP barn with a pasture-based system will increase net returns due to improved animal performance and reduced cost per unit of milk. However, tradeoffs may exist. For example, the increased bedding costs for zero-grazing herds can increase overall costs and may reduce long-term profitability of investing in the CBP barn. Also, constructing a new barn can generate more income through improved labor efficiency. However, investing in the CBP barn may not be feasible due to the greater capital requirements. Evaluating these tradeoffs can help farmers make informed decisions when investing in this new housing technology. To provide insights into this situation, a study of the compost bedded dairy housing technology in a pasture-based system was conducted using a partial budget analysis approach.
Materials and Methods

To assess the economic viability of the compost bedded pack housing, a partial budget was developed in excel. The model inputs were obtained from Katete commercial dairy farm in Lilongwe, Malawi before (March to August, 2016) and during a 6 mo study (March 1 to August 30 2017). Katete farm 35 multiparous lactating Holstein-Friesian cows were housed in a compost bedded dairy barn, a loose housing system (Janni et al., 2007). The new housing facility was built to provide primary housing for lactating dairy cows. Before the study began, cows were housed in a conventional cubicle dairy housing (Figure 4.1). The new housing (Figure 4.2) was a renovated conventional cubicle dairy barn with an attached feed alley and concrete exercise area.

The compost bedded pack barn (Figure 4.2) design included; an open composted pack, feed alley, waterers, and a 1.2 m retaining wall to separate the pack from the feed alley. The pack lying space per cow was 9.71 m$^2$. The bedded pack length (m) and width (m) were measured using a laser (Robert Bosch Tool Corporation, Mt. Prospect, IL, USA). The composted dairy barn was initially bedded with 50 cm of sawdust (Galama, 2009). Sawdust bedding was added based on the moisture guideline for composted beds (40 to 60%) (NRAES, 1992). The pack was tilled twice daily to provide a clean and dry resting area (Janni et al., 2007).

Animal Management

This study was conducted during the rainy and dry seasons (March to August 2017). Grazing systems (in which cows are allowed access to pasture for a greater proportion of day) and semi-grazing systems (in which cows are kept indoors with or without outdoor access) were employed during the 6 mo study. Cows at the study farm were fed forages and a concentrate as described by (Chizonda, 2015).
For both the grazing and semi-grazing, concentrate was fed in the parlor during milking (8 kg per cow split between morning, 0200h and evening, 1600h milking). For the semi-grazing, cows were allowed to graze for 16.67% of the day and were supplemented with Napier grass (*pennisetum purpureum*) mixed with maize bran and molasses. Feed intake was assumed to increase gradually with a gradual increase in milk production (Black, 2013).

**Data Collection**

During the farm visits, fixed costs, daily and monthly farm income, and variable costs were collected by the study personnel. The variable costs consisted of labor, health (veterinary consultation charges and cost of veterinary medicines), feed, straw and sawdust bedding, and manure handling costs. Fixed costs consisted of barn construction, depreciation, interest on average value, and repair costs.

Farm income consisted of milk sales, manure, bonus for high milk fat, and bonus for low bacteria count in milk. To assess changes in income and in costs after cows transition into the CBP (March to August, 2017), actual income from milk sales and manure, variable cost (sawdust bedding cost, straw bedding cost, feed cost (concentrate, and non-marketed Napier grass cost), labour cost, CCD manure hauling and spreading cost, CBP barn tillage cost, mastitis costs (veterinary consultation charges and cost of veterinary medicines), and fixed costs (CBP initial barn costs, depreciation, interest on average value, and repair costs) during the study (6 mo) were collected by the study personnel. To the extent possible, some costs and income measures were collected during the previous year (March to August, 2016) by the study personnel. The costs consisted of health (veterinary consultation charges and cost of veterinary medicines), milk yield, milk sales, feed costs, CCD straw bedding cost, CCD manure hauling and spreading costs, and labor costs.
Farm income consisted of milk sales, manure revenue, bonus for high milk fat, and bonus for low bacteria count. If no records were available, the income and variable cost were calculated based on relevant scientific literature. Information from experts within the Malawian Dairy Industry and the authors’ expertise were used if literature was not available.

**Partial Budget Analysis**

Partial budgeting is an important tool for farm decision making. For example, partial budgeting can be used to analyze farm decisions, including adopting a new technology, buying farm machinery, and investing in capital improvement. The framework compares the costs and benefits of alternatives. Partial budgeting allows farmers to understand how a decision will affect their farm profitability. Investment evaluation includes the consideration of fixed and variable costs.

Profitability for the CBP housing system was determined by calculating expected increase and decrease in revenue and in costs. These revenues and costs were compared for 6 months before moving into the CBP barn (March to August, 2016) and 1 to 6 months (February 20 to August, 30, 2017) after moving into the CBP barn. Economic benefits were associated with increased milk production, low bacteria count, improved manure quality, reduced labor costs of handling liquid manure, reduced mastitis, reduced costs of barn replacement, and repairs (Table 4.2). The average exchange rate (Malawi Kwacha to 1 US dollar) during the 6-month study was K715 to 1 US $.

**Economic Benefits**

**Milk Production**

The mean milk production, days in milk, and milk fat for the CCD barn and the CBP barn are presented in Table 4.1. Thirty-five cows were housed in the CCD barn. The herd size was assumed to be the same for the 6 months before moving into the CCD barn.
Milk production was determined by averaging weekly production of Holstein-Friesian dairy cows for 6 mo before and after moving into the CCD barn. Milk production increase was calculated as daily increase in milk production per cow (kg) multiplied by the number of cows, and the study period (180 d). The total milk production increase for the 6-month study was calculated using Equation 1.1:

\[
\text{MILK}_I = \text{MILK}_D \times \text{MILK}_{PC} \times \text{COW}_L \times 180
\]  
(Eq. 1.1)

Where \(\text{MILK}_I\) is the total milk production increase, \(\text{MILK}_D\) is the mean daily milk production (kg) per cow, \(\text{MILK}_{PC}\) is the percent change in milk production (%), \(\text{COW}_L\) is the number of lactating cows housed in the CBP barn, and 180 is the number of days during the study.

Milk price was determined using a 5-year average ($0.49/kg, NSO, 2016). While milk price in Malawi varies seasonally, with higher prices in the dry season, production levels offset this pattern resulting in somewhat stable total milk revenue (NSO, 2016). Increase in milk income was calculated as increase in milk production multiplied by milk price ($/kg), and the study period (180 d) using Eq.1.2.

\[
\text{MILK}_R = \text{MILK}_I \times \text{MILK}_P \times 180
\]  
(Eq. 1.2)

Where \(\text{MILK}_R\) is the increase in milk income ($) from increased milk production, \(\text{MILK}_I\) is the total milk production increase, \(\text{MILK}_P\) is the 5-year average milk price in Malawi, and 180 is the number of days cows were housed in the CBP barn during the study.

**Fat Content**

To determine fat content, composite milk samples (5 ml) were collected bi-weekly during milking and analyzed for milk fat on a Milk-Lab (Milk-Lab Compact, Lancashire, United Kingdom). In Malawi, when a farmer delivers milk to a processor, milk is subjected to a chemical test (fat, protein, and total solids). Milk with a 3.25% or greater fat content receives a bonus based on the harmonized standards for the Common Market for Eastern and Southern
Africa (COMESA) (Foreman, 2013). The harmonized COMESA Standard milk fat is estimated at 3.25% (Foreman, 2013). To determine change in revenue due to improved milk fat, monthly milk fat bonus was averaged for the 6 months before CBP barn occupation and was compared to averaged milk fat bonus for 6 months after moving into the CBP barn. Increased revenue from bonus on milk fat > 3.25 percent was calculated using Equation 1.3:

$$ BONUS_{FC} = BONUS_{FA} - BONUS_{FB} \quad (Eq. \ 1.3) $$

Where \( BONUS_{FC} \) is the change in revenue ($) due to bonus on milk fat > 3.25%, \( BONUS_{FA} \) is the total bonus on milk butter fat after moving into the CBP barn, \( BONUS_{FB} \) is the total bonus on milk fat >3.2% before moving into the CBP barn.

**Milk Quality**

In Malawi, milk that is delivered at a processing plant is tested for bacteriological quality (total bacterial count). A bonus is applied on milk with total bacteria count < 2.0 \( \times \) 10^5 colony forming units (CFU/ml) based on harmonized COMESA standard. Increased revenue due to milk with bacteria count < 2.0 \( \times \) 10^5 CFU/ml was calculated as the average change in bonus and was calculated using Equation 1.4:

$$ BONUS_{QRC} = BONUS_{A} - BONUS_{B} \quad (Eq. \ 1.4) $$

Where \( BONUS_{QRC} \) is the change in revenue ($) due to bonus on quality (low bacteria count in milk, < 2.0 \( \times \) 10^5 CFU/mL), \( BONUS_{A} \) is the bonus on low bacteria count after moving into the CBP barn, \( BONUS_{B} \) is the bonus on low bacteria count before moving into the CBP barn.

**Manure Revenue**

Compost samples were collected from nine locations on the CBP bedded pack (Figure 4.2) at the end of September, 2017. Samples were analyzed at the Lilongwe University of Agriculture and Natural resources (LUANAR) Soil Science Laboratory in Lilongwe for carbon, nitrogen, and phosphorus. Compost bedded pack manure was stored for 9 months (Janni et al., 2007).
Compost nitrogen and phosphorus were 2.30% and 0.31%, respectively. Manure N and P of 0.44% and 0.15%, respectively was assumed for the CCD barn. These N and P values were based on value of manure >6 month storage in the field (Table 4.1). Dairy cattle manure for the CCD barn is often piled in an open field (Chizonda, 2015). With this manure management system, it was assumed that all the ammonium-N was lost after 9-month storage.

Generally, a total of 50% N and P is lost from manure on an open field through runoff and volatization. The nitrogen and phosphorus values were used to calculate the manure revenue for the CCD barn and CBP barn. Nitrogen and phosphorus are important to produce maize, sorghum, and pastures in Malawi. For the CBP, manure revenue after clearing the CBP in September, 2017 was calculated based on nutrient content of the CBP barn compost N and P after compost samples were analyzed at the LUANAR Soil Science Laboratory in Lilongwe in September, 2017. With the CBP manure, compositing stabilizes the manure.

For the CCD housing, equivalent nitrogen and phosphorus metrics were calculated based on stored manure N and P, taking into consideration nutrient losses during storage. The cost of N and P in the CBP compost and CCD stored manure were based on 5-year (2012 to 2017) fertilizer prices of $0.51 per kg N and $0.51 per kg P, respectively, as published by the National Statistics Office in Malawi (Table 4.1).

The change in manure revenue from before to after housing cows in the CBP was calculated using Equation 1.5:

$$ MV_{RC} = MR_{RA} - MR_{RB} $$

Where $MV_{RC}$ is the expected change in manure revenue ($), $MR_{RA}$ is the manure revenue after moving into the CBP barn, and $MR_{RB}$ is the manure revenue before moving into the CBP barn.
**Reduced Costs**

**Mastitis Costs**

Mastitis is a complex and costly health problem on dairy farms worldwide. Economic losses from mastitis can result from decreased milk production, discarded milk, veterinary consultation charges, cost of veterinary medicines, and labor costs (Nielsen and Østergaard, 2009). To assess the economic cost of mastitis, mastitis prevalence (the number of cows that suffered from mastitis at a given point) and incidence (the number of new mastitis cases that developed over the study period) were calculated for the 6 months before and 1 to 6 months after moving into the CBP barn. Because no organized recording scheme exists in Malawi (Chagunda et al., 2006), clinical mastitis events, veterinary costs, and discarded milk (due to mastitis) for the 6 mo before cows moved to the CBP (March to August, 2016) were collected from farm records.

The farmer was asked to improve on-farm record keeping for the CBP clinical mastitis events, veterinary costs, and discarded milk (due to mastitis) throughout the 6-month study. Mastitis prevalence for 6 months before moving into the CBP barn was estimated at 68% (Table 4.1) based on (Tebug, 2012). The estimated mastitis prevalence rate of 68% (Tebug, 2012) was equivalent to mastitis prevalence rate of 66% of CCD-housed cows during the 6 mo study. Average milk production loss due to mastitis was estimated at 11% (Nielsen and Østergaard, 2009).

Increased somatic cell count (>200,000 cell/mL) is associated with mastitis in the dairy herd. Composite milk samples were collected weekly during the 6 mo study and analyzed for SCC on Ekomilk scan somatic cells analyzer (Ekomilk scan, BULTECHC 2000, Sweden). Teat ends were washed and dried using a clean cloth; teats were fore-stripped, pre dip was applied and removed with a clean cloth, and teats were cleaned with 70% isopropyl alcohol swab before drawing a 5 ml sample. Quarter milk samples were pooled and mixed thoroughly before
drawing a single sample (10 ml) for SCC analysis. Mastitis prevalence of cows housed in the CBP barn was calculated as the number of animals with a test SCC >200,000 cells/mL divided by the total number of animals. Clinical mastitis events in the CBP during the study were used to calculate the mastitis incidence rate for the CBP barn.

The expected decrease in costs due to reduced mastitis incidence and prevalence for the CBP barn was calculated as the difference in total cost of mastitis for the 6 mo before and 6 mo after transitioning into the CBP barn. Total losses due to clinical mastitis were calculated using Equation 1.6

\[ \text{LOSS}_E = \text{LOSS}_{MR} + VET_C + COST_D \]  

(Eq. 1.6)

Where \( \text{LOSS}_E \) is the total economic loss due to clinical mastitis, \( \text{MILK}_R \) is the loss in milk revenue ($202.49) due to reduced milk production, \( VET_C \) is the costs of veterinary consultation and veterinary medicines, and \( COST_D \) is the cost ($) of discarded milk ($).

The cost of discarded milk due to clinical mastitis was calculated using Equation 1.7:

\[ \text{COST}_{DM} = \text{MASTITIS}_I \times COW_H \times \text{MILK}_Y \times \text{MILK}_P \times \text{DAYS}_D \]  

(Eq. 1.7)

Where \( \text{COST}_{DM} \) is the cost of discarded milk due to mastitis ($), \( \text{MASTITIS}_I \) is the average incidence of clinical mastitis in cows, \( COW_H \) is the number of cows, \( \text{MILK}_Y \) is the average daily milk yield of cows (kg), \( \text{MILK}_P \) is the milk price ($), and \( \text{DAYS}_D \) is the number of days milk is discarded.

The milk production revenue loss was calculated using Equation 1.8:

\[ \text{LOSS}_{MR} = \text{MASTITIS}_{PL} \times COW_S \times \text{MASTITIS}_I \times \text{MASTITIS}_D \times \text{MILK}_Y \times \text{MILK}_P \]  

(Eq. 1.8)

Where \( \text{LOSS}_{MR} \) is the total loss in milk revenue due to reduced milk production ($), \( \text{MASTITIS}_{PL} \) is the average milk production loss due to mastitis (%), \( COW_S \) is the proportion of cows housed in the CCD barn that were sick from mastitis, \( \text{MASTITIS}_I \) is the average incidence of mastitis in cows, \( \text{MASTITIS}_D \) is the average duration of mastitis, \( \text{MILK}_Y \) is the
average daily milk yield of cows (kg), and MILKP is the milk price ($). The expected reduced cost from reduced mastitis cases was calculated using the Eq. 1.9:

\[\text{COST}_{CM} = \text{COST}_{MA} - \text{COST}_{MB}\]  
(Eq. 1.9)

Where COST\text{CM} is the change in mastitis cost after moving from the CCD barn into the CBP barn, COST\text{MA} is the cost of mastitis after moving into the CBP barn ($), and COST\text{MB} is the cost of mastitis before moving into the CBP barn ($).

**Manure Handling Costs**

Labor requirements to rake stalls, scrape the feed alley, scrape exercise areas, gather straw bedding from the field, and transport liquid manure to the field can increase costs for the CCD barn. Data on number of workers per barn (CBP and CCD), workers monthly wages, and number of hours of doing daily chores were collected 6 mo before and 6 mo after cows moved to the CBP. The CCD and CBP workers monthly wages were calculated using a 5-year labor cost per man-hour of $0.13 published by the National Statistics Office in Malawi (Table 4.1). Labor costs (rake stalls, scrape feed alley and exercise areas, gather and add straw bedding to the stalls, and transport manure to the field) for the CCD shed was calculated using Equation 1.10:

\[\text{COST}_{TL} = \left\{ \left[ \frac{\text{RAKE}_T + \text{SCRAPE}_T + \text{SB}_T + \text{MANURE}_T}{60} \right] \times \text{COST}_H \right\} \times 180 + (\text{MANURE}_F \times 180) \]

(Eq. 1.10)

Where COST\text{TL} is the total labor cost to rake stalls, scrape exercise areas, gather bedding and add bedding, and transport manure to the field for the CCD barn, RAKE\text{T} is the daily average time required to rake the stalls (m), SCRAPE\text{T} is the average time required to scrape the exercise areas and feed alley (m), SB\text{T} is the daily average time required to gather straw bedding and add to the stalls, MANURE\text{T} is the daily average time to transport manure to the field, 60 converts m to h, COST\text{H} is the labor cost per hour, 180 is the number of days for the study, and MANURE\text{F} is the average cost of fuel to transport manure.
The expected decrease in manure handling costs due to benefits associated with improved manure management for the CBP barn (Black, 2013) compared with the CCD barn was calculated as the difference in total costs of manure management for the 6 months before and 6 months after transitioning into the CBP barn. A CBP barn can be an effective manure storage system. Black et al. (2013) found that on average, producers removed manure from the composted pack 1.7 ± 0.8 times per year. Removing manure once a year can reduce the cost of handling manure. Manure in the present study was removed after 9 months (January to September, 2017).

Labor costs (stirring the pack, scraping the feed alley, adding sawdust bedding, and transporting compost to the field) for the CBP barn was calculated using Equation 1.11:

\[
COST_{TL} = \left[ \left\{ \frac{\text{SCRAPE}_T + \text{BP}_{TF}}{60} \right\} \times COST_H \right] \times 180 + SDC + MANURE_F
\]

(Eq. 1.11)

Where \(COST_{TL}\) is the total labor cost for manure management, \(\text{SCRAPE}_T\) is the total labor cost to scrape the feed alley, \(\text{BP}_{TF}\) is the average time required to till the pack twice a day (m), 60 converts m to h, \(COST_H\) is the labor cost ($0.13 per h), 180 is the number of days for the study, \(SDC\) is the labor cost ($0.13 per h) for sawdust addition (calculated as time required to add sawdust to the pack [m] multiplied by frequency of sawdust bedding addition [9 times]), and labor cost, ($0.13 per h), and \(MANURE_F\) is the cost ($) of fuel to transport compost ($16.74). Manure handling costs were reduced from $1,096.23 to $507.77 (data not shown) after moving into the CBP.

Equation 1.12 was used to calculate the change in manure management costs after moving into the CBP barn for the 6-month study:

\[
COST_{LM} = COST_{LA} - COST_{LB}
\]

(Eq. 1.12)

Where \(COST_{LM}\) is the change in manure handling costs ($) after moving into the CBP barn, \(COST_{LA}\) is the cost of handling manure after moving into the CBP barn ($), and \(COST_{LB}\) is the cost of manure management before moving into the CBP barn.
Total Decreased Costs

Total expected decrease in cost due to decreased mastitis costs, barn repair and replacement costs, and manure handling costs was calculated using Equation 1.13:

\[ COST_{ED} = MC_D + MANURE_D + BARN_{RR} \]  \hspace{1cm} (Eq. 1.13)

Where \( COST_{ED} \) is the total expected decreased costs for the 6 months, \( MC_D \) is the decrease in mastitis costs due to decrease in mastitis prevalence after moving into the CBP barn, and \( MANURE_D \) is the decrease in cost of handling manure from the decrease in manure scraping and storage costs, and \( BARN_{RR} \) is the expected decrease in cost of barn repair and replacement.

Total Increased Income

Total expected increase in income was calculated using Equation 1.14:

\[ INCOME_{TI} = MILK_R + BONUS_Q + BONUS_C + MV_R \]  \hspace{1cm} (Eq. 1.14)

Where \( INCOME_{TI} \) is the total expected increase in income for the 6 months, \( MILK_R \) is the revenue ($) from milk production ($1,960.9), \( BONUS_Q \) and \( BONUS_C \) are the expected increase in revenue ($) from the milk quality (low bacteria count) bonus ($15) and milk composition bonus ($7.5), respectively, and \( MV_R \) is the expected increase in income after selling manure.

Economic Costs

Compost Bedded Pack Barn Costs

The compost bedded dairy barn had high side walls, a bedded pack, a 1.2 m retaining wall, a feed alley, exercise area, and eaves overhung. The compost bedded pack provided 9.71 m² of lying space per cow (Figure 4.2). Because of the moisture input from urine, feces, and microbial decomposition, large space per cow is required in the CBP barn to increase the area for moisture evaporation per cow (Janni et al., 2007). The farmer in the current study renovated an old barn with a concrete feed alley and concrete exercise area.
Sawdust Bedding Cost

To start the CBP barn, sawdust bedding (50 cm deep) was evenly distributed in the bedded pack (Galama, 2009). The 50 cm deep bed is required so that tillage equipment has enough depth to function during tillage and to absorb the moisture from cow feces, urine, and microbial decomposition (Galama, 2009). Initial bedding costs were calculated as a bedding depth of 50 cm (at the beginning of the CBP) multiplied by bedded pack area (310.8 m²), and bedding cost per cubic meter. Subsequent bedding costs were calculated as the added bedding (10 cm) multiplied by pack area (310.8 m²), frequency of new sawdust bedding addition (9 times), and bedding cost per cubic meter ($0.86 per m³).

During the study, a total of 397.57 m³ sawdust bedding was used. The cost of bedding for CCD barn was expected to be lower than bedding costs for CBP barn. The non-marketed price of straw bedding for the CCD barn was estimated based on daily cost of labor ($0.13 per h, NSO, 2016) needed to collect straw bedding and addition of bedding in the stalls.

Total bedding cost for the CBP barn was calculated as initial bedding cost plus added bedding costs during the rainy and dry seasons using Eq. 1.15 (Black, 2013):

\[
C_{TB} = SD_{IC} + (AMOUNT_{D} \times BARN_{A} \times FREQ_{T} \times COST_{SD}) \quad \text{(Eq. 1.15)}
\]

Where \(C_{TB}\) is the total cost ($) of sawdust bedding during the study (March to August, 2017), \(SD_{IC}\) is the initial sawdust cost ($122.86 for 141.99 m³ of sawdust), \(AMOUNT_{D}\) is the average amount (10 cm) of sawdust bedding per bedding addition, \(BARN_{A}\) is the bedded pack area (386.24 m²), \(FREQ_{T}\) is the frequency of bedding additions (9 times), and \(COST_{SD}\) is the cost ($) of sawdust bedding per m³.
Feed Costs

Cows at the study farm were fed Napier grass (*pennisetum purpureum*) mixed with maize bran and molasses in the barn and a concentrate in the parlor. Non-marketed feed cost (cost of Napier grass; *pennisetum purpureum*) fed as a cut- and- carry feed in the CBP barn under semi-grazing system was calculated as the labor cost ($0.13 per hour, NSO, 2016) required for cutting and transporting Napier grass (under a semi-grazing system). The commercial dairy farm formulated concentrates based on maize bran, rice bran, soybean, sunflower cake, and mineral premixes (Chizonda, 2015). The 5 y estimated costs of the feed ingredients (maize bran, rice bran, soybean, sunflower cake, and mineral premixes ) and molasses were used to calculate the cost of the added feed due to an increase in DMI of 0.68 kg DM for the milk yield increase of 0.7 kg per cow/ day. Feed intake was assumed to increase gradually with a gradual increase in milk production (Black, 2013).

The dry matter intake was calculated using Eq. 1.16, anticipating 75%, 85%, and 100% change in performance for the first, second, third, and all other years, respectively (Black, 2013):

\[
\text{DMI} = FCM \times FE \times MPC
\]  
(Eq. 1.16)

Where DMI is the dry matter intake (kg dry matter per cow) for the increased milk production per cow (kg per day), FCM is the fat-corrected milk (kg), and the FE is the feed efficiency ratio, and MPC is the percent of change in milk production.

Fat-corrected milk was calculated using Eq. 1.17 (NRC, 2001):

\[
FCM = (0.4 \times \text{Milk}) + (15 \times \text{MILK} \times \text{FAT})
\]  
(Eq. 1.17)

Where FCM is 4% fat corrected milk (kg), MILK is the calculated daily increase in milk production (kg), and FAT is the fat content of the milk (%).
Total increase in costs of the CBP barn, sawdust bedding, and increased feed costs was calculated using Equation 1.19:

\[ COST_{TI} = COST_{IB} + COST_{SB} + COST_{F} \]  \hspace{2cm} (Eq. 1.19)

Where \( COST_{TI} \) is the total increased costs for the 6 months, \( COST_{IB} \) is the initial barn cost, \( COST_{SB} \) is the sawdust bedding cost ($0.86 per m\(^3\) ), and \( COST_{F} \) is the cost of added feed because of increase in feed intake for the increased milk production (0.7 kg per cow/day).

**Tax on added income**

In Malawi, businesses including commercial farms and small dairy producer associations are required to pay tax on all profits. The average 5-y income tax rate (20%) (NSO, 2016, Table 4.1) was used to calculate tax. The taxable income was calculated using Equation 1.20.

\[ INCOME_{TAX} = INCOME_{EI} - COST_{TI} \]  \hspace{2cm} (Eq. 1.20)

Where \( INCOME_{TAX} \) is the taxable income, \( INCOME_{EI} \) is the total increase in income ($), and \( COST_{TE} \) is the total expected costs ($).

Total income tax was calculated using Equation 1.21:

\[ TOTAL \, TAX_{I} = INCOME_{TAX} \times TAX_{R} \]  \hspace{2cm} (Eq. 1.21)

Where \( TOTAL \, TAX_{I} \) is the total tax on taxable income ($), \( INCOME_{TAX} \) is the taxable income ($), and \( TAX_{R} \) is the tax rate.

Expected increase in costs was calculated using Equation 1.22:

\[ COST_{EI} = COST_{TI} + TOTAL \, TAX_{I} \]  \hspace{2cm} (Eq. 1.22)

Where \( COST_{EI} \) is the expected increase in costs, \( COST_{TI} \) is the total increase in costs and \( TOTAL \, TAX_{I} \) is the total tax on taxable income ($).
**Net Return**

The net return of investing in a compost bedded pack barn was calculated as the economic benefits minus the costs. When the net return was greater than or equal to zero, the investment decision was considered viable. When the net return was less than zero, the investment decision was considered not viable, meaning that the benefits of the decision did not outweigh costs.

The net return was calculated using Equation 1.23.

\[
    \text{RETURN}_N = \left( \text{INCOME}_{EI} + \text{COST}_{ED} \right) - \left( \text{COST}_{EI} + \text{INCOME}_{ED} \right)
\]

(Eq. 1.23)

Where \( \text{RETURN}_N \) is the net return, \( \text{INCOME}_{EI} \) is the expected increase in income ($), \( \text{COST}_{ED} \) is the expected decrease in costs ($), \( \text{COST}_{TI} \) is the expected increase in costs, and \( \text{INCOME}_{ED} \) is the expected decrease in income due to moving into a CBP barn.

**Payback period**

Payback period estimated the length of time necessary to payback on the investment in the alternative compost bedded pack housing in a pasture-based production system. The payback period was calculated as the CBP barn cost divided by the net income over a 10 year investment period (useful life of the CBP barn).

The payback period was calculated using using equation 1.24.

\[
    PP = \frac{\text{COST}_B}{\sum_{n=1}^{10} \text{CASH FLOW}_n}
\]

(Eq. 1.24)

Where \( PP \) is the payback period, \( \text{COST}_B \) is the CBP barn cost ($), \( \text{CASH FLOW} \) is the net cash flow ($) for a given year, 10 is the investment period in years, and \( n \) is the production year, where \( n = 0 \), is the initial investment year for the CBP barn.
Scenarios and Sensitivity Analysis

Scenarios

Three scenarios were evaluated: the default scenario and two alternative scenarios. Economic and biological variables for the default scenario (CBP combined with grazing system ("systems in which cows are kept at pasture for a large proportion (33.33 to 41.67% of the day) of the day) and semi-grazing system (systems in which cows are kept indoors with (16.67% of the day) or without outdoor access) are presented in Table 4.1. The total cost of constructing the new CBP barn without a feed alley was $5,368.75. The cost of the CBP barn per cow space of 9.71 m² was $536.87. The cost of sawdust bedding was $1.49 per day (Table 4.1). The average milk production increased from 10.20 ± 0.6 kg to 10.92 ± 0.5 kg after moving into the CBP barn with cows housed under both the grazing and semi-grazing system (Table 4.1).

The first alternative scenario considered a CBP housing system with cows managed under a semi-grazing system ("systems in which cows are kept at pasture for a large proportion (33.33 to 41.67% of the day). For this scenario, it was assumed that a CBP barn with a feed alley was constructed. Due to the added cost of concrete for the feed alley, the total initial cost of the CBP barn increased (Black, 2013). The total cost of constructing the new CBP barn with a feed alley was $5,629.98.

The cost of the CBP barn per cow space of 9.71 m² was $579.81. With the semi-grazing system, cows were at pasture for 16.67% of the day. Thus, increased cost of handling manure and bedding was assumed. Also, for this scenario, increased manure revenue was assumed due to improved manure N and P of the CBP compost. The added revenue from improved manure N and P of CBP compost was estimated at $151.28. The added cost of handling manure was $365.41. Mastitis prevalence was 51% and the milk yield was 10.9 ± 0.5 kg per day (data not shown).
The second alternative scenario considered a CBP barn with a grazing system. With the grazing system, cows were at pasture for approximately 33.33 to 41.67% of the day. Thus, a reduced cost of handling manure was assumed. The cost of handling manure was estimated at $254. The added income from reduced costs of handling manure was $842. Because allowing pasture access reduces the amount of urine and manure voided while in the barn (Black, 2013), reduced bedding requirements were assumed. Due to reduced bedding requirements, the estimated total cost of sawdust bedding was $230. The estimated cost of sawdust bedding per day was $0.47. Mastitis prevalence and milk yield were 50% and 12.15 ± 4kg per day, respectively (data not shown).

Sensitivity Analysis

Sensitivity analysis was performed to determine how robust the estimated values were compared with the initial values (Table 4.3 and Figure 4.5). Sensitivity analysis suggests a range of prices or costs at which a technology becomes profitable (Mutsaers et al., 1986). Sensitivity was performed by varying values using the “Goal Seek” tool in Excel (Microsoft Excel 2010, Microsoft, Seattle, Washington). Sensitivity analyses allowed the variable of interest to vary while all values in the default scenario were held constant. Two sets of analyses were performed. For the first analysis, the effect of individual economic and biological variables (Figure 4.5) on net returns was determined. These biological variables were milk yield and mastitis prevalence. The values higher or lower than the default for milk yield were +10 and -10% and +20 and -20% for mastitis prevalence. For the economic variables, higher or lower values were assessed. These values were $0.60 and $0.24/kg for milk price, $0.10 and $0.23 per hour for labor costs associated with manure handling, and $0.44 and $2.0 per day for sawdust bedding costs.
The second sensitivity analysis determined how different variables for the default scenario (CBP combined with both the grazing and semi-grazing system, Table 4.3) affected the net returns. For each variable, a range of possible values was investigated. These variables were mastitis prevalence (20% to 80%), bedding material costs ($0.8 to $1.6 per day), barn cost per cow space ($200 to $600), and milk yield increase (4% to 16%).

**Results**

**Partial Budget Analysis**

The partial budget analysis results for the default scenario (CBP barn with grazing and semi-grazing systems) are presented in Table 4.2. The net return of investing in a CBP barn during the 6-month study was $880.70 for the default scenario. This net return represented a daily net return of $4.90. The initial CBP barn cost was $5,368.75. Because the farmer renovated an old barn with an attached concrete feed alley, the initial barn cost did not include the feed alley cost. The cost of sawdust bedding was $1.43 per day. The marginal savings from mastitis costs and the cost of handling manure were $345 and $588.5, respectively. The revenue from selling milk and manure were $1,959.2 and $126.6, respectively. Compost N for the CBP barn was 2.30%, which was 80.9% greater than N percentage in CCD manure. Phosphorus was 0.31%, which was 51.6% greater than P value in CCD manure. The total revenue (revenue + reduced costs) was estimated at $3,136 (Figure 4.4).

For the CBP barn with a semi-grazing system, the net return of investing in a CBP barn for the 6 months was $504.6 (Figure 4.4). In this scenario, the daily net return of investing in a CBP barn was $2.8. The estimated initial barn cost with an attached feed alley was $5,629.98. At this initial CBP barn cost, the added cost of the feed alley was $261. The added cost of sawdust bedding was $1.5 per day. The total added cost was $2,285. Mastitis prevalence and milk yield
were 52% and 11.77 kg per day for the 6 months (data not shown). The total savings from mastitis and manure handling costs were $235 and $842, respectively. The total added revenue for the 6 months was $2,789.8 (Figure 4.4). For the CBP barn with a grazing system, the net return of investing in a CBP barn was $1,077.9 (Figure 4.4). In this scenario, the net daily net return of investing in a CBP barn was $6. Mastitis prevalence and milk yield were 50% and 12.15 kg per day for the 6 months (data not shown). The added health cost was $349. The total savings from reduced costs of sawdust bedding ($0.96 per day) and manure handling was $1,164.4. The total added revenue was $3,652 (Figure 4.4).

**Payback period**

Payback period analysis showed that the benefits of the CBP over CCD are $ 1425 per year, but it would take an investment of $5368. The farmer would be expected to pay back the investment in 3.77 years.

**Sensitivity analysis**

The results for the sensitivity of the net returns of investing in compost bedded pack barn to variation in inputs for a commercial dairy herd transitioning from conventional cubicle dairy barn are presented in Figure 4.5. The results for the first sensitivity analysis showed that a higher milk yield of +10% resulted in a net return of $1,988.6 for investing in a new housing system, which is 55.7% greater than the default scenario (CBP combined with both the grazing and semi-grazing system). Also, a higher milk price ($0.60 per kg) resulted in greater net returns of $1,232.6. A higher rate of mastitis infection prevalence (+50%) decreased the net return by $465.8 for the 6 months. Higher sawdust bedding costs ($2.00 per day) and higher initial CBP barn costs ($700 per cow space) resulted in lower net returns of $744.70 and $364, respectively, compared with the default scenario (CBP combined with grazing and semi-grazing system, Figure 4.5).
The net returns at a higher labor cost ($0.23 per hour) and lower labor cost ($0.10 per hour) were $1,009.9 and $1,485, respectively. These net returns for the higher and lower labor costs were greater compared with the default scenario (CBP combined with grazing and semi-grazing system), indicating that the net returns were insensitive to changes in labor costs. The results for the second sensitivity analysis are presented in Table 4.3. For milk yield increases of 4%, 8%, 12%, and 16%, net returns of investing in a CBP barn were $367.60, $1,513.50, $2,763.60, and $4,132.70, respectively. For mastitis prevalence of 20%, 40%, 60%, and 80%, the net returns of investing in a CBP barn were $1,366.60, $1,053.20, $739.70, and $426.20, respectively. For sawdust bedding material costs of $0.80, $1.00, $1.20, $1.40, and $1.60 per day, the net returns were $1,032.70, $984.70, $936.70, $888.70, and $840.70, respectively.

The initial compost bedded dairy barn cost had an effect on the net returns. With a higher initial CBP barn cost of $700 per cow space, the net returns were $364, which is 58.7% lower than that of the default scenario. With a lower CBP barn initial cost of $200 per cow space, the net returns were $1,500, which is 41.3% greater than the default scenario (CBP combined with grazing and semi-grazing system). The breakeven values of sawdust bedding materials ($ per day), initial CBP barn cost per cow space, and milk yield increase (%) were $5.10, $860.20, and 2.6%, respectively (Table 4.3).

**Discussion**

Our study used the partial budget analysis approach to assess the economic viability of investing in a new housing system in a commercial dairy farm setting in central Malawi. The partial budget included economic costs and revenues associated with an investment decision to build a compost bedded pack barn. However, the partial budgeting approach provides a limited assessment of risk. Also, inputs used in the partial budget analysis were deterministic, therefore
not able to capture uncertainty associated with the decision to invest in a new housing system. A further limitation of our study is that changes in revenue due to improved reproductive performance, cow comfort, and low lameness in the CBP barn were not included in the partial budget as these changes occur gradually and are difficult to measure. The subjects in this study served as their own control, thereby providing detailed insight into the newer housing concept, the compost bedded pack barn. Single-system studies are often used in applied research to investigate the effect of an intervention (Evance et al., 2006). Further investigations on the CBP are needed using more farms to increase the power.

In all scenarios, the initial CBP barn cost was too great to be absorbed by the added revenue from increased milk production and improved manure revenue during the 6 months. Consequently, the initial 1-year equivalent cost of the CBP barn including depreciation and interest was used. Despite these challenges, the economic assessment using the partial budget approach provides important estimates of net returns of investing in a new housing technology, the compost bedded dairy barn, in the tropics when the CBP barn is combined with either grazing or semi-grazing management systems.

The net return of investing in a CBP barn in the default scenario was $880.70 (Table 4.2). This net return indicates that combining a CBP barn with grazing and semi-grazing systems is profitable. The net return increased due to increased revenue from milk yield, manure, bonus on milk fat and low milk bacteria count, and reduced costs (costs of mastitis due to low mastitis prevalence and mastitis incidence, manure handling, barn repairs and replacement). The increased milk yield (Table 4.1) increased the total income. Changes in maintenance requirements due to confinement when the CBP barn was managed under the semi-grazing system, coupled with cow comfort in the CBP barn, could have increased the milk yield. Cow stress caused by diseases (Kawonga et al., 2012), reduced lying time (Banda, 2014), and excessive manure and mud (Tebug, 2012) in the CCD barn, will generally lead to an increase
in energy expended for maintenance. Manure revenue increased due to increased manure quality (nitrogen and phosphorus content) for the CBP barn. The average carbon, nitrogen and phosphorus percentage of CBP compost after 6 months was 9.12%, 2.30%, and 0.31%, respectively. In the CCD housing system, manure handling methods, including heaping under shed, heaping without shed, and direct application to fields (Muhereza et al., 2014), tends to reduce manure nitrogen (N) content. However, Whitney and Lynch (1996) observed that nitrogen can be a limiting nutrient in compost from CBP barns because of high carbon content from bedding materials. In our study, N and P values for the CBP barn compost were similar to values for dairy cow manure and to those reported by Black (2013) at 1.7% and Barberg et al. (2007) at 2.5%, respectively for CBP barn compost.

Mastitis costs for the CBP barn were reduced due to reduced mastitis prevalence. On average mastitis prevalence in the CBP barn was 51% (Table 1), which is 25% lower than mastitis prevalence before moving into the CBP barn with a variation between 0% and 100% (minimum and maximum). Researchers expect mastitis infection prevalence to decrease after moving into the CBP barn due to improvements in management (Barberg et al., 2007, Black, 2013). Barberg et al. (2007a) found that mastitis prevalence decreased by 21.75% (from 35.4% to 27.7%) after moving into CBP barns.

Black (2013) assessed the viability of investing in a CBP barn in 47 dairy farms and concluded that it was viable to invest in a CBP housing system. However, direct comparison of the two studies is difficult because of differences in the production systems and the period of assessment of the CBP barns. Black estimated that milk yield increased by 2.6 kg/cow per day after moving into the CBP barn, based on Barberg et al. (2007a). In our study, milk yield increased by 6 percent, which is 30% lower than that of Barberg et al. (2007a) and Black (2013), with 10% increase from 12 months to 1 to 12 months after moving into the CBP barn. Production changes may occur more gradually after moving into a CBP barn (Black, 2013).
Also, comparing this change in milk yield with the result of is difficult, as the two farming systems differ (Moran, 2005). In our study, the herd was under grazing and semi-grazing systems. The herds in the previous studies (Barberg et al., 2007a, Black, 2013) were in confinement after moving from pasture or freestalls. Because of the greater management requirements for CBP housing compared with pasture, Black, (2013) estimated a greater milk yield increase (2.6 kg per day). Furthermore, Black (2013), assessed the viability of investing in a CBP barn using net present value for a period of 10 years. Whereas the net present value considered the risk of investment and the time value of money, the partial budget analysis provides only limited assessment of risk. In this analysis, economic and biological variables collected within the study period for the CBP barn (6 months) were considered.

Further, our study assessed the viability of investing in a CBP barn combined with a grazing system or a CBP barn with a semi-grazing system. Black (2013) assessed the economic viability of a CBP barn where cows were kept in confinement. To our knowledge, ours is the first study that has assessed the economic viability of a CBP barn with a grazing system or semi-grazing system. The economic results for the default scenario (CBP with grazing and semi-grazing system; Figure 4.4), shows that the total savings from reduced costs contributed 32.78% to the total added revenue. With the total costs being greater than the added income for the default scenario, savings form reduced costs such as the costs of mastitis and manure management are an important part of the net returns of investing in compost bedded dairy barn. By combining the CBP barn with a grazing or semi-grazing system, the combined benefits of reduced bedding requirements and low mastitis prevalence increased the total added income and subsequently increased the net returns. However, the availability and subsequent cost of sawdust bedding can increase the costs in the long run (Bewley and Taraba, 2013).

The partial budget analysis (Figure 4.4) for the CBP barn combined with grazing management revealed that it was viable to invest in a CBP barn with a grazing management system. For this
scenario, it was shown that the total revenue was $3,652, which is 14% greater than that of the default scenario and 27.5% greater than the CBP barn with the semi-grazing management system. While milk price varies seasonally, higher prices in the dry season (NSO, 2016) and the higher production levels in the CBP barn with the grazing system scenario offset this pattern, resulting in somewhat stable total milk revenue. By combining the CBP barn with a grazing system, the net returns of investing in the new housing technology increased. The net returns were $1,077.9, which are 18% greater than the default (CBP with grazing and semi-grazing system) and 53% greater than the CBP barn with the semi-grazing system.

For the CBP barn combined with the semi-grazing system, the net return of investing in a CBP barn was $504.6, indicating a positive investment scenario. However, this net return was lower compared with net returns for the default scenario ($808.7) and the CBP barn with the grazing system scenario ($1,077.9).

For many decades, commercial dairy farms in Malawi have managed their herds under grazing (Chagunda et al., 1999). However, in recent years, semi-grazing systems are increasing in commercial dairy farms (Chizonda, 2015) and so is the need for better housing systems (Kawonga et al., 2012). With semi-grazing management systems, important trade-offs exist. For example, cows in semi-grazing systems are provided with supplementary feed in the barn (cut-and-carry). The cut-and-carry method can increase the labor costs. However, semi-grazing allows herds to minimize losses (milk production and altered milk composition) due to low maintenance requirements for cows under confinement compared with cows under a grazing system. Also, the added revenue from manure for the CBP barn with the semi-grazing system (data not shown) was greater than the default scenario (CBP with grazing and semi-grazing system, Table 4.1), due to improved manure quality.
In the default scenario (CBP with grazing and semi-grazing system), the total reduced costs for mastitis, liquid manure handling, stall management, and barn replacement and repairs was $1,039.58, indicating that the dairy farm saved money for using the CBP barn with grazing and semi-grazing systems. However, the added feed cost of $0.55 per cow per day and sawdust bedding cost of $1.43 per day increased the costs.

**Conclusion**

Because of increased milk yield, manure value, milk fat, reduced costs of mastitis, manure handling, and barn replacement and repairs, an investment in CBP housing in a pasture-based system in Malawi was profitable considering the default scenario. However, increased feed costs due to increased milk production and increased bedding costs partially offset these benefits. Both the CBP barn with a grazing system and a CBP barn with a semi-grazing system showed positive net returns, indicating that investing in a CBP barn with a grazing or semi-grazing system was profitable. For the CBP barn with the semi-grazing system, the cost of the feed alley added to the expenses for the herd. However, the increased milk revenue and manure sales may offset these costs in the long run.

Net returns were affected by the barn cost, milk price, milk yield, and mastitis prevalence. However, the net returns of investing in CBP housing were more sensitive to barn cost per cow, milk price, and milk yield increase (%). Investment in compost dairy housing becomes less profitable when milk production and milk prices are low. The benefits of the CBP over CCD are $1425 per year, but it would take an investment of $5368. The producer would be expected to pay back in 3.77 years. The economic results showed that the compost bedded pack housing was viable within the pasture-based system.
Improvements in milk yield, manure quality, low SCC, and low mastitis prevalence, and reduced manure handling cost showed the benefits of compost bedded housing technology. These improvements can be disseminated to producers via extension service. However, before it is presented on a large scale through the extension system, it may be necessary to adjust some recommendations (e.g. bedded pack space per cow) based on the current breeds, climate, and management system (grazing and semi-grazing system). Further, to provide an indication of the actual value of the new housing technology, monitoring and evaluating the adoption rate by a wider dairy farming community would be necessary. Overall, the farm was satisfied with the cleanliness of cows, and relatively lower SCC of CBP-housed cows compared with the CCD-housed cows. Because cows in the CBP were consistently clean, milkers in the parlor often spent less time removing dirt. However, due to the on-going sawdust cost, the farm preferred to use the CBP barn to house small number of animals such as sick cows or heifer calves. These factors must be taken into account when deciding whether to invest in an alternative compost bedded pack housing system.
Table 4.1: Variables used in the partial budget analysis: default scenario (CBP combined with both grazing and semi-grazing system) settings

<table>
<thead>
<tr>
<th>Variable</th>
<th>CCD Input</th>
<th>CBP Input</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax rate (%)</td>
<td>20</td>
<td>20</td>
<td>NSO, 2016</td>
</tr>
<tr>
<td>Interest rate (%)</td>
<td>30</td>
<td>30</td>
<td>NSO, 2016</td>
</tr>
<tr>
<td>Useful life of housing (years)</td>
<td>3 to 5</td>
<td>15 to 20</td>
<td>Thomas et al., 1994</td>
</tr>
<tr>
<td>Bedding cost ($ per day)</td>
<td>0.13</td>
<td>1.49</td>
<td>Malawian Dairy expertise</td>
</tr>
<tr>
<td>Milk production (kg/cow per day)</td>
<td>10.20</td>
<td>10.92</td>
<td>Kawonga, 2012, Banda, 2014</td>
</tr>
<tr>
<td>Dry matter intake (kg DM)</td>
<td>11.3</td>
<td>11.4</td>
<td>Malawian Dairy expertise</td>
</tr>
<tr>
<td>Milk production loss due to mastitis</td>
<td>11%</td>
<td>11%</td>
<td>Nielsen, 2009</td>
</tr>
<tr>
<td>Barn cost per cow space ($)</td>
<td>585</td>
<td>472.7</td>
<td>Malawian Dairy expertise</td>
</tr>
<tr>
<td>Mastitis prevalence rate (%)</td>
<td>68</td>
<td>51</td>
<td>Tebug, 2012</td>
</tr>
<tr>
<td>Labor costs ($ per hour)</td>
<td>0.13</td>
<td>0.13</td>
<td>NSO (2012 to 2017)</td>
</tr>
<tr>
<td>Feed cost ($ per kg DM)</td>
<td>0.55</td>
<td>0.55</td>
<td>NSO (2012 to 2017)</td>
</tr>
<tr>
<td>Non-marketed feed costs ($)</td>
<td>55</td>
<td>55</td>
<td>NSO, 2015</td>
</tr>
<tr>
<td>Milk price ($/kg)</td>
<td>0.55</td>
<td>0.55</td>
<td>NSO, 2015</td>
</tr>
<tr>
<td>Fat content</td>
<td>3.0</td>
<td>3.45</td>
<td>Mankhwala, 2014, Malawian Dairy expertise</td>
</tr>
<tr>
<td>Protein content</td>
<td>2.8</td>
<td>3.0</td>
<td>Mankhwala, 2014, Malawian Dairy expertise</td>
</tr>
<tr>
<td>Bonus on fat (%) and low bacterial count (CFU/ml)</td>
<td>$0.51</td>
<td>$0.51</td>
<td>Muhereza et al., 2014, NSO, 2015</td>
</tr>
</tbody>
</table>
Table 4.1. Cont.

1 Cost for conventional cubicle dairy barn was calculated as cost of labor per hour ($) to cut and carry straw bedding.

2 Mastitis prevalence was calculated as the number of animals with a test somatic cell count >200,000 cells/mL divided by the total number of animals evaluated weekly (Barberg et al., 2007). Cows with a test somatic cell count >200,000 cells/mL were considered infected.

3 Non-marketed feed cost was calculated as the cost of labor per hour ($) to cut and carry Napier grass for feeding cows under the semi-grazing system.

4 Bonus payment based on Common Market for Eastern and Southern Africa (COMESA, Foreman, 2013) guidelines of >3.25% fat or <2.0 x 10^5 colony forming units (CFU) per mL.

5 Manure nitrogen (N) and phosphorus (P) for the CCD barn was assumed to be 0.44% and 0.15%, respectively (Muhereza et al., 2014). Manure revenue was calculated based on equivalent fertilizer N and P 5 y prices in Malawi ($0.51 per kg, NSO, 2016).

NSO = National Statistics Office, CBP = Compost bedded dairy barn, CCD = conventional cubicle dairy barn.
Table 4.2. Economic results for the default scenario, expressed as increased and reduced revenue and costs, during 6-month study at a commercial dairy farm in Malawi

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Added costs ($ for 6 months)</strong></td>
<td></td>
</tr>
<tr>
<td>Annualised CBP barn cost</td>
<td>1,073.8</td>
</tr>
<tr>
<td>Tax on increased income</td>
<td>391.84</td>
</tr>
<tr>
<td>Interest on capital</td>
<td>53.69</td>
</tr>
<tr>
<td>Feed cost due to increased milk yield</td>
<td>64.0</td>
</tr>
<tr>
<td>Sawdust bedding costs ($)</td>
<td>344.0</td>
</tr>
<tr>
<td>Depreciation</td>
<td>258.0</td>
</tr>
<tr>
<td>Tillage equipment repairs</td>
<td>15.0</td>
</tr>
<tr>
<td>Non-marketed feed cost</td>
<td>55.0</td>
</tr>
<tr>
<td><strong>Total added costs</strong></td>
<td>2,255.3</td>
</tr>
<tr>
<td><strong>Revenues ($ for 6 months)</strong></td>
<td></td>
</tr>
<tr>
<td>Manure revenue</td>
<td>126.7</td>
</tr>
<tr>
<td>Milk income</td>
<td>1,959.2</td>
</tr>
<tr>
<td>Bonus on low bacteria count ($)</td>
<td>15.0</td>
</tr>
<tr>
<td>Bonus on milk fat &gt; 3.25% ($)</td>
<td>7.5</td>
</tr>
<tr>
<td><strong>Total added returns</strong></td>
<td>2,108.4</td>
</tr>
<tr>
<td><strong>Reduced costs</strong></td>
<td></td>
</tr>
<tr>
<td>Barn replacement: cost</td>
<td>70.0</td>
</tr>
<tr>
<td>Barn repairs: Yearly cost</td>
<td>24.0</td>
</tr>
<tr>
<td>(^1)Mastitis costs</td>
<td>345.1</td>
</tr>
<tr>
<td>(^2)Manure handling</td>
<td>588.5</td>
</tr>
<tr>
<td><strong>Total reduced costs</strong></td>
<td>1,027.6</td>
</tr>
<tr>
<td><strong>Total added revenue</strong></td>
<td>3,135.9</td>
</tr>
<tr>
<td><strong>Net returns ($ for 6 months)</strong></td>
<td>880.7</td>
</tr>
<tr>
<td><strong>Net returns ($ per cow)</strong></td>
<td>25.9</td>
</tr>
</tbody>
</table>

\(^1\)Clinical mastitis cost was calculated as the sum of reduced milk production, veterinary consultation charges, cost of veterinary medicines, and cost of discarded milk (Singh and Singh, 1994). Average milk production loss due to mastitis was estimated at 11 % (Nielsen, 2009).
Table 4.3. Sensitivity of net returns to investment in a compost bedded dairy housing in a pasture-based system at different milk yield increase, costs of bedding, barn cost, and labor cost

<table>
<thead>
<tr>
<th>Variable</th>
<th>Net returns ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk yield increase (kg per day)</td>
<td></td>
</tr>
<tr>
<td>0.48</td>
<td>367.60</td>
</tr>
<tr>
<td>0.98</td>
<td>1,513.50</td>
</tr>
<tr>
<td>1.54</td>
<td>2,763.60</td>
</tr>
<tr>
<td>2.15</td>
<td>4,132.70</td>
</tr>
<tr>
<td>Breakeven milk yield increase</td>
<td>0.31 kg/cow per day</td>
</tr>
<tr>
<td>Sawdust bedding cost/m^3</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>1,032.7</td>
</tr>
<tr>
<td>1.0</td>
<td>984.7</td>
</tr>
<tr>
<td>1.2</td>
<td>936.7</td>
</tr>
<tr>
<td>1.4</td>
<td>888.7</td>
</tr>
<tr>
<td>1.6</td>
<td>840.7</td>
</tr>
<tr>
<td>Breakeven sawdust bedding cost</td>
<td>$5.05 per m^3</td>
</tr>
<tr>
<td>1 CBP barn cost per cow space</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1,500</td>
</tr>
<tr>
<td>300</td>
<td>1,272.8</td>
</tr>
<tr>
<td>400</td>
<td>1,045.6</td>
</tr>
<tr>
<td>500</td>
<td>818.4</td>
</tr>
<tr>
<td>600</td>
<td>591.2</td>
</tr>
<tr>
<td>Breakeven CBP barn cost</td>
<td>$860.2 per cow space</td>
</tr>
<tr>
<td>Mastitis prevalence (%)</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>1,366.6</td>
</tr>
<tr>
<td>40</td>
<td>1,053.2</td>
</tr>
<tr>
<td>60</td>
<td>739.7</td>
</tr>
<tr>
<td>80</td>
<td>426.2</td>
</tr>
</tbody>
</table>

^1Space per cow was calculated as compost bedded pack area divided by total number of cows housed in the compost bedded dairy barn.
Figure 4. 1. Conventional cubicle dairy cattle barn layout with feed manger, waterers, stalls, and exercise area
Figure 4. 2. Compost-bedded pack barn layout with bedded pack, walkways, waterers, and feed alley
Figure 4. 3: Map of Malawi showing the location of Lilongwe
Figure 4.4: The economic results for the default scenario (compost bedded dairy barn under grazing and semi-grazing system), compost bedded dairy barn under semi-grazing system, and compost bedded dairy barn under grazing system.
Figure 4.5: Sensitivity of the net returns of investing in compost bedded dairy (CBP) barn to variation in inputs for a commercial dairy herd transitioning from conventional cubicle dairy housing into compost bedded pack housing.
Chapter Five: Compost pack performance, dairy cattle udder health, and economic viability of compost bedded pack housing in a pasture-based production system

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Abstract

Improving housing for dairy cattle is of interest because hoof and udder health, which are associated with the housing environment, are important economic and welfare issues. The objectives were: 1) to assess the influence of housing—conventional cubicle dairy (CCD) barn vs compost bedded pack (CBP) barn,—and management (grazing vs semi-grazing) on the performance and welfare in dairy cows 2) describe the performance of the CBP housing under a grazing or semi-grazing system, and 3) to assess viability of CBP housing in a pasture-based system in Malawi. To achieve these objectives, this study mixes three research approaches, an analysis of existing and secondary data; an experiment, and a case-study. If taken out of context and used in isolation, this mix of methods would lead to ambiguity and confusion. But in the context of the Malawi dairy industry, it is by mixing these methods that we can best inform farmer’s decisions about the type of structures that best serve them individually and the
Malawian dairy industry as a whole. The mean compost bed moisture (41.81 ± 8) was within the optimal moisture range for efficient composting. However, bed temperature increased gradually with the greatest bed temperature of 43.3°C observed in wk 23. With low bed temperature (30.89 ±7.5°C) as observed in this study, microbial diversity in the bed increases, reducing the efficiency of composting. Cows housed in the CBP produced 1.2 kg more milk per cow/day than cows in CCD and exhibited lower hygiene scores (1.52 ± 0.04 vs 1.8 ± 0.04) than cows in the CCD. Sub-clinical high SCC prevalence and somatic cell counts were 22.72 % and 48.32% lower in CBP barn compared with CCD barn. Results of the partial budget analysis revealed that the CBP was viable with net returns of $881. Exchange rate for 1 US dollar was 715 Malawi Kwacha. Thus the benefits of the CBP over CCD are $ 1425 per year, but it would take an investment of $5368. The farmer would be expected to pay back the investment in 3.77 years.

Keywords: Compost bedded dairy housing, cow performance, economic viability,

Introduction

A single-system study was designed to assess the effect of housing systems (CCD and CBP) on dairy cattle performance and welfare, assess the performance of CBP in a pasture-based system, and evaluate economic viability of alternative compost bedded pack housing system in a pasture-based production system in one commercial dairy herd in Lilongwe, Malawi (Southeast Africa). Two different management systems were maintained on the farm; grazing system (“systems in which cows are kept at pasture for a large proportion (8 to 10 h; 33.33 to 41.67% of the day) of the day) and semi-grazing system (systems in which cows are kept indoors with (16.67% of the day) or without outdoor access).
Assessment of cow welfare (lameness, hock lesions, hygiene, udder health) and performance in the CCD or CBP were performed weekly for 24 weeks (March 1 to August 30, 2017). The assessment period were grouped as; rainy season grazing (wk 1 to 4), rainy season semi-grazing (wk 6 to 9), dry season grazing (wk 11 to 16), and dry season semi-grazing (wk 18 to 23). For this study, primary data on somatic cell count, milk yield, locomotion scores, hygiene scores, and hock lesions scores were collected for 6 mo.

Four treatments (rainy season grazing; wk 1 and 3, rainy season semi-grazing; wk 7 and 9, and dry season grazing; wk 13, 15 and 17, and dry season semi-grazing (wk 21 and 23) were applied sequential to examine the influence of management system on compost bedded pack characteristics. For this study, primary data on compost temperature, moisture, pH, and carbon to nitrogen ratio were collected for 6 mo.

A partial budget was developed in excel to assess the viability of the alternative compost bedded pack housing in a pasture-based system. Primary data on cow performance (milk yields, somatic cell count, milk components, incidence of clinical mastitis), CBP manure quality (nitrogen, potassium, and phosphorus), economic costs (veterinary costs, labour costs, barn building and repair costs, bedding cost, feed costs), and revenue (milk, manure) were collected 6 mo before and after implementing the CBP housing system. Secondary sources of data (CCD barn construction and repair costs, CCD mastitis prevalence, CCD manure quality, milk price, and DMI) included published literature and Malawi Dairy Industry Expert information. This chapter provides a summary of these three studies.

**Results and Discussion**

Temperature and moisture are crucial factors determining the success of composting process (NRAES, 1992). Moisture is a principal factor affecting temperature changes in bed because of its high specific heat capacity compared to other materials. In this study, bed moisture
content was greater during the rainy season compared with the dry season. Moisture content during the dry season under both the grazing and semi-grazing system (38.65% and 33.46%, respectively) remained on the lower end of the optimal moisture content for composting (40 to 60%). The greatest moisture difference between the rainy and dry season was when cows were managed under the semi-grazing system. The maximum bed temperature (43.3°C) and moisture content (52.10%) were observed when cows were managed under the semi-grazing system.

The CBP moisture under the semi-grazing (52.10 ± 0.71) fell within the recommended range for the top 15 cm (50.7 ± 8.8%) (Janni et al., 2006, Barberg et al., 2007a), indicating that CBP under the semi-grazing system might have resembled an efficient composting bed with a gradual increase in both temperature and moisture content. Similar to the observed low mean bed temperature (30.08 ± 6.60) in the current study, LeBlanc and Anderson (2013) noted that most compost barns were managed at moisture of 30% or less, indicating that the barns did not heat well. A known consequence of low bed moisture content is lack of water for microbial proliferation, slowing the decomposition rate (Bewley et al., 2013, LeBlanc and Anderson, 2013). However, managing CBP for good composting allows proliferation of pathogens such as coliforms, Staphylococcus, Streptococcus, and Bacillus species in the pack (Black et al., 2014). With a proper balance of organisms in the compost bed however, organisms might competitively inhibit pathogens in the feces (Petzen et al., 2009).

Several studies (Barberg et al., 2007, Black et al., 2013) have shown that SCC improves over time for cows after transitioning into compost barns. The trends in SCC and the mean SCC showed that SCC was lower in the CBP compared with the CCD barn. The greatest difference \((P = 0.02)\) in SCC between the two housing systems (CCD and CBP) was during the dry season with cows managed under semi-grazing system. However, the mean SCC for cows housed in both housing (CCD and CBP) during the dry season was greater than 600,000 cells/mL,
indicating udder infection with major pathogens. With SCC > 600,000 cells/mL, there is a risk
that milk yield will decrease due to increasing SCC (El-Tahawy and El-Far, 2010), reducing
the gains associated with increased milk yield for the CBP barn. The benefits of the CBP over
CCD are $1425 per year, but it would take an investment of $5368. The farmer would be
expected to pay back the investment in 3.77 years. The average exchange rate was 715 Malawi
Kwacha to 1 US dollar.

By combining the CBP barn with a grazing and semi-grazing system, the combined benefits of
reduced bedding requirements and low labor costs increased the total added income and
subsequently increased the net returns. However, the availability and subsequent cost of
sawdust bedding can increase the costs in the long run (Bewley and Taraba, 2013).

The economic results for the default scenario (CBP with both grazing and semi-grazing
systems) (Figure 4.4), shows that the total savings from reduced costs contributed 32.78% to
the total added revenue. With the total costs being greater than the added income for the default
scenario (CBP with both grazing and semi-grazing systems), savings form reduced costs such
as the costs of mastitis and manure management are an important part of the net returns of
investing in CBP housing. Sensitivity analysis showed that net returns to investment in the CBP
housing were sensitive to mastitis prevalence. A higher rate of mastitis infection prevalence
(+50%) decreased the net return by $465.8 for the 6 months. Therefore, focus on reducing SCC
in preventing mastitis infection will be critical in implementing the compost bedded dairy barn
as an alternative housing option in Malawi.
Recommendations

1. The current research suggests that milk yield would be increased by improving animal housing such the use of an alternative compost bedded pack housing system.
2. Further studies are required on the long-term effects of housing cows in the conventional cubicle housing with sand and straw bedded stalls on cow hygiene and udder health.
3. The compost bedded pack housing system needs to be tested using more definitive assessment with cows housed under confinement. Combining the results of the current study in a meta-analysis to improve the power could be another option.

Conclusion

The effects of housing and management systems on performance and welfare in dairy cows were examined on a single farm. Therefore, the results should not be generalized to a larger population. This study design was chosen for the purposes of obtaining data on the compost bedded pack barn, which is a newer housing concept (Janni et al., 2007). The subjects in the study of the effect of management (grazing vs semi-grazing system) for the conventional cubicle housing served as their own control, thereby providing detailed insight into the emerging management system (semi-grazing system).

The partial budgeting approach provides a limited assessment of risk. Also, inputs used in the partial budget analysis were deterministic, therefore not able to capture uncertainty associated with the decision to invest in a new housing system. The choice of this study design combining three research approaches, an analysis of existing and secondary data; an experiment, and a case-study allowed us to obtain data on the performance of the alternative compost bedded pack housing in a pasture-based system. To our knowledge, ours is the first study that has assessed the economic viability of a CBP barn with a grazing system or semi-grazing system. Results of this study can be disseminated through extension. However, before it is presented.
on a large scale through the extension system, it may be necessary to adjust some recommendations (e.g. bedded pack space per cow) based on the current breeds, climate, and management system (grazing and semi-grazing system). Further, to provide an indication of the actual value of the new housing technology, monitoring and evaluating the adoption rate by a wider dairy farming community would be necessary.

Acknowledgement

This material is based upon work supported by the United States Agency for International Development, as part of the Feed the Future initiative, under the CGIAR Fund, award number BFS-G-11-00002, and the predecessor fund the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013. The authors thank all the staff and management at the University of Kentucky in the USA, staff and management at Katete Commercial Dairy farm and staff at Central Veterinary Laboratory in Lilongwe for their help during the study.
### Table 5.1: Descriptive statistics of compost bed temperature, compost bed moisture content, and outside air temperature

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1Bed temperature (°C)</td>
<td></td>
<td>24</td>
<td>43</td>
<td>31</td>
<td>7.50</td>
</tr>
<tr>
<td>2Bed moisture (%)</td>
<td></td>
<td>29</td>
<td>54.0</td>
<td>41.3</td>
<td>8.30</td>
</tr>
</tbody>
</table>

1Bed temperature (°C) was measured at the center of the nine equally divided areas on the bedded pack at 20 cm depth using a probe.

2Compost moisture content was calculated as the wet weight minus dry weight divided by the dry weight minus the container weight. Percent moisture content was calculated as moisture content multiplied by 100.

SD = Standard deviation
Table 5.2. Least square means (± SE) from the mixed model analysis showing the effect of housing system on hygiene scores, somatic cell count, sub-clinical high SCC, lameness, and milk yield

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Housing system</th>
<th>SEM</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CCD barn</td>
<td>CBP barn</td>
<td></td>
</tr>
<tr>
<td>1Hygiene scores</td>
<td>1.80</td>
<td>1.52</td>
<td>0.05</td>
</tr>
<tr>
<td>2SCC (x10^3 cells/mL)</td>
<td>1045.16</td>
<td>540.16</td>
<td>76.84</td>
</tr>
<tr>
<td>3Sub-clinical high SCC (%)</td>
<td>65.73</td>
<td>51.36</td>
<td>0.03</td>
</tr>
<tr>
<td>Milk yield (kg/d per cow)</td>
<td>9.69</td>
<td>10.89</td>
<td>0.57</td>
</tr>
<tr>
<td>4Lameness (%)</td>
<td>0.69</td>
<td>0.04</td>
<td>0.01</td>
</tr>
</tbody>
</table>

1Cow hygiene was evaluated weekly by the same observer using a 1 to 4 hygiene scoring system (1= clean, 4 = dirty)
2Somatic cell counts were analyzed weekly. Cow milk SCC was log transformed to obtain a linear score using the following equation; SCC = Log2 (SCC/100000) +3).
3Sub-clinical high SCC prevalence was calculated as the number of cows with a test SCC >200,000 cells/mL divided by the total cows each week
4Cows were evaluated weekly for lameness using a 1-3 locomotion scoring system (1= sound: 3 = severely lame) by the same observer at the exit of the milking parlor while cows walked on a flat surface. Lameness prevalence was calculated by dividing the number of cows with a locomotion score of 3 by the total number of cows scored each week (Barberg et al., 2007a).

CCD = Conventional cubicle dairy barn; CBP = Compost bedded pack barn
Table 5.3. Economic results for the default scenario, expressed as increased and reduced revenue and costs, during 6-month study

<table>
<thead>
<tr>
<th>Variable</th>
<th>CCD Input</th>
<th>CBP Input</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax rate (%)</td>
<td>20</td>
<td>20</td>
<td>NSO, 2016</td>
</tr>
<tr>
<td>Useful life of housing (years)</td>
<td>3 to 5</td>
<td>15 to 20</td>
<td>Thomas et al., 1994</td>
</tr>
<tr>
<td>Bedding cost ($ per day)</td>
<td>0.13</td>
<td>1.49</td>
<td></td>
</tr>
<tr>
<td>Milk production (kg/cow per day)</td>
<td>10.20</td>
<td>10.90</td>
<td>DAHLD, 2016, Chizonda, 2015, Banda, 2014</td>
</tr>
<tr>
<td>Dry matter intake (kg DM)</td>
<td>11.3</td>
<td>11.4</td>
<td>Chizonda, 2015, Mtimuni, 2011</td>
</tr>
<tr>
<td>Milk production loss due to mastitis</td>
<td>11%</td>
<td>11%</td>
<td>Nielsen, 2009</td>
</tr>
<tr>
<td>Barn cost per cow space ($)</td>
<td>585</td>
<td>472.7</td>
<td>Malawian Dairy expertise</td>
</tr>
<tr>
<td>Mastitis prevalence rate (%)</td>
<td>68</td>
<td>51</td>
<td>Tebug, 2012</td>
</tr>
<tr>
<td>Labor costs ($ per hour)</td>
<td>0.13</td>
<td>0.13</td>
<td>NSO (2012 to 2017)</td>
</tr>
<tr>
<td>Feed cost ($ per kg DM)</td>
<td>0.55</td>
<td>0.55</td>
<td>NSO (2012 to 2017)</td>
</tr>
<tr>
<td>Non-marketed feed costs ($)</td>
<td>55</td>
<td>55</td>
<td>NSO, 2015</td>
</tr>
<tr>
<td>Milk price ($/kg)</td>
<td>0.55</td>
<td>0.55</td>
<td>NSO, 2015</td>
</tr>
<tr>
<td>Fat content</td>
<td>3.0</td>
<td>3.45</td>
<td>Mankhwala, 2014, Malawian Dairy expertise</td>
</tr>
<tr>
<td>Protein content</td>
<td>2.8</td>
<td>3.0</td>
<td>Mankhwala, 2014</td>
</tr>
<tr>
<td>Bonus on fat (%) and low bacterial count (CFU/ml)</td>
<td>19.5</td>
<td>22.5</td>
<td>Foreman, 2013</td>
</tr>
<tr>
<td>Manure revenue ($ per kg N or P) N</td>
<td>0.51</td>
<td>0.51</td>
<td>Muhereza et al., 2014</td>
</tr>
<tr>
<td>= 0.44%, P = 0.15% for CCD and N</td>
<td></td>
<td></td>
<td>NSO, 2015</td>
</tr>
<tr>
<td>= 2.31%, P = 0.31% for the CBP</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5.1. Conventional cubicle dairy cattle shed layout with feed manger, stalls, and exercise area
Figure 5.2. Compost bedded pack barn layout with bedded pack, walkways, waterers, and feed alley
Figure 5.3. Weekly milk production of loose-housed dairy cows during the rainy and dry seasons. CCD = conventional cubicle dairy barn; CBP = Compost bedded pack barn
Figure 5.4. Weekly somatic cell counts in milk samples of loose-housed dairy cows during the rainy and dry seasons. CCD = conventional cubicle dairy barn; CBP = Compost bedded pack barn


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VITA

Betty Kawonga was born in Blantyre, Malawi (Southern East Africa). Betty obtained her Bachelor of Science degree in Animal Science and Master of Science Degree in Animal Science from the University of Malawi. Her Master’s research was on characterizing smallholder dairy production systems and developing a cow performance monitoring tool for smallholder dairy farms. In 2014, Betty obtained a PhD scholarship from the American Government under the USAID Feed the Future BHEARD Scholars Program. In fall of 2014, Betty began studying for her PhD under the direction of Dr. Jeffrey Bewley, and later under the direction of Dr. Melissa Morgan, studying the economic viability of alternative compost bedded pack housing in a pasture-based system and the effect of housing and management systems on cow performance, udder health, and well-being. Betty worked as a teaching assistant in Dairy Science course at the University of Kentucky and as a Lecturer in Dairy Science at the Lilongwe University of Agriculture and Natural Resources in Malawi. She served as a member in the University of Kentucky Omicron Delta Kappa Leadership Honor Society, College of Agriculture Gamma Sigma Delta Honor Society, and Animal and Food Science Graduate Student Association. Betty is a Borlaug Higher Education in Agricultural Research and Development (BHEARD) Fellow, 40 Chances Fellow, and African Women in Agricultural Research and Development (AWARD) Fellow. She has published 2 papers in peer reviewed journals, contributed to 1 peer reviewed journal, and 3 conference proceedings.