Dairy Compost Bedding Pack Barns

Literature Review

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For Subtropical Dairy Ltd

Comfortable cows on compost bedding in Nth. USA. Source *Progressive Dairyman* 29 September 2017

Abstract

Compost Pack Bedding (CPB) relies on an aerobic process to decompose cow waste in the bedding, producing heat, water and CO2 from the pack. The composting process relies on pack bacteria being kept in an active phase, where the pack heat and adequate ventilation are essential to allow for water loss from the pack as evaporation. Design and construction of barns must focus on adequate natural and forced ventilation and keeping solar radiation and exogenous water off the pack. Packs are generally removed and replaced annually.

CPB Barns are used widely in USA, in the cold climates of the northern states, and to a lesser degree in Europe and Britain, to improve cow comfort, welfare and longevity. These are mostly smaller farms, averaging 80 milking cows/farm. CPB Barns are also utilized extensively in Israel in larger herds, where the climate is hot and dry, and Recycled Manure Solids (RMS) are commonly utilized as bedding. In the USA, recommended bedding is sawdust and wood shavings, and these products are becoming less available and more expensive. More research is being conducted into alternative bedding. These systems must be managed well to be successful. Better management practices to promote effective bacterial composting, include aeration by pack tilling 2 – 3 times daily, keeping pack area/cow above $10m^2$ /cow, daily monitoring of pack moisture, pack temperature, cow cleanliness, cow comfort, cow distribution and incorporating new bedding material or reducing cow numbers when pack moisture is too high or temperature too low.

There is little published information available on the use of CBP systems in tropical and subtropical environments, however anecdotal evidence suggests that many CPB systems are now being converted to free-stall sheds on large commercial farms in SE Asia.

When working effectively, these systems provide good cow comfort, good oestrous detection, and no increase in clinical mastitis levels. However, these packs do not eliminate mastitis organisms from the pack, and good milking management techniques are vital, to reduce risks of increased mastitis and SCC. CPB barns are generally well accepted by the public and are seen as providing very good welfare conditions for the cows.

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1. Introduction

Dairy farming in Australia has been traditional pasture based, with development in more recent times, of Partial Mixed Ration (PMR) and Total Mixed Ration (TMR) systems, to reduce input variables, and especially to minimise climatic and seasonal availably in forage and nutrition for cows. To reduce input variables further and to assist in management, housing of cattle is becoming more common in Australia.

Compost bedding barns are now common in USA for housing dairy cattle. These are now being built in Australia, for various reasons. There is currently little information available in Australia, on building and managing these systems, and this Literature Review, in associations with case studies from Australia, is designed to develop an information package for Australian farmers. The aim of this package is for Australian farmers to be better informed when making decisions about building dairy housing and shelter systems, particularly in relation to local environmental conditions, construction, costs, constraints and operation of these systems in Australia. Most of the literature cited comes from northern USA.

2. Cow Housing

Dairy cattle have been used for milk production for human consumption for over 2,000 years (1), and cows were originally confined only at night, as protection from predators.

Modern dairy cow management systems however, confine cows for many other reasons, and these confinement systems are becoming more sophisticated, as herds are become larger, and developing in many different climatic zones (3).

2.1 Outdoors - Pasture

Most milk in Australia is still produced from pasture, with some nutritional supplementation. Cattle are generally provided shade if required, and artificial cooling when cattle are at the milking parlour. Otherwise, most cattle spend most of their time at pasture.

In the USA, in general, cows on when managed well pasture-based dairying systems, compared to housed systems, have lower feed production costs, and positive health and welfare outcomes, particularly with respect to improved; lying times; lameness and reproductive outcomes (2). Some poorer lameness and mastitis outcomes have been identified in Australian systems, where cattle walk long distances, especially in wet conditions (44). Many pasture systems become difficult to manage with large numbers of cows, especially under conditions of high temperature, rainfall and if cattle are walking long distances.

2.2 Confinement

2.2.1 Definition

Animal housing is generally referred to as confinement

The Oxford dictionary defines confinement as *"to keep or restrict someone or something within certain limits of (space, scope, or time)."* With respect to cattle, this could be in a yard, shed, under shade etc.

2.2.2 Confinement Reasons

There are many reasons why farmers confine cattle, including attempting to (3);

- Control the physical environment, including protection from wind, rain, snow, heat, solar radiation, predators (eg calves);
- Reduce energy use by cattle, by bringing feed to one site and reducing cattle walking to pasture;
- Higher milk volume production;
- Easier management of larger number of cattle on one site;

- Better pasture/forage and soil management, as cattle are not damaging yard, forage plants or soil;
- Cleaner cows and improved milk quality;
- Improve cow comfort;
- Control diseases and parasites, (eg some ticks);
- Manage effluent and run-off.

Successfully achieving these outcomes will depend on the design, environmental suitability and operational management of the confinement system used (3).

2.3 Types of Confinement (Housing)

There are a number of different types of housing bedding systems that have been developed over the last 60 years. These are usually covered barn systems.

<u>Barn design</u> (for any housing system) will vary depending on reason for building the barn, local environment, local authority compliance, cow heat tolerance, natural air flow, barn use, full time or part-time housing, cost of construction and access to other facilities (13). Natural air flow should be adequate in all barns (12), to allow for cow cooling, and to remove moisture, methane and ammonia. Barn position is also important to allow the best use of natural air movement. To maximise natural air flow, barns should be spaced well apart, high enough, have a reasonable amount of roof slope, have a continuous ridge gap, and preferably have full side wall opening. The barns should preferably be built in an East-West orientation, to prevent direct sunlight entering the barn. Curtains may be necessary to reduce wind exposure during cold periods in some areas.

Fans will also be necessary in most barns, especially in times when the Temperature Humidity Index (THI) is above 72, with sprinklers (in low humidity) or misters over the Feed bunk and also fans over the cows resting areas (free-stalls or loose-houses) (14). Barn design is discussed more specifically in 3.2; *CPB Barn Design and Construction*.

2.3.1 Conventional Bedding Pack Barns (BP)

These systems are generally covered yards, with a base of gravel (or cement) generally being laid down to prevent leeching (3). Straw bedding is generally utilized to provide absorption for urine and faeces and a dry bed for the cow. The bedding (4) remains unturned and topped-up 1-2 times daily. The systems can be built with or without feed bunks and concrete alleyways, depending on their use and other facilities that are available.

Thurgood J.M. 2009 (4) indicated that this type of loose housing with bedding (usually straw), offering an area of 7 – 10 m^2/cow, has been utilized since the 1950s and are still commonly used today, especially in Britain. If managed well, and in comparison with free-stall barns, the BP housing (3) at 10m^2/cow, generally achieve better cow comfort, with very high lying times. They can accommodate animal of different size, have a lower capital cost, have higher oestrous detection rates, and have lower levels of lameness, with the exception of white line separation and heel ulcers in heifers (4). However, these systems become difficult to manage on a large scale (above 70 cows), and many converted sheds with low roofs may result in bedding becoming deep and difficulty for machinery to remove soiled bedding, as well as poor ventilation, mastitis, lameness and respiratory disease (4). These BP barns require less specialised operational knowledge or pack maintenance, when compared with compost barns, and provide a simple solid effluent storage system. Generally, all bedding is removed twice annually and is excellent material for composting (4) for soil conditioning and garden use.

J. M. Bewley et.al. 2017 (3) reported that an upper layer moisture content of <15% is required to maintain cow cleanliness, low cell counts and cow health. To maintain this environment, additional bedding is required, ranging from 4.5kg - 15.9kg (up to 18) kg/cow per day.

This can quickly erode the advantage of low capital cost and can also encourage the operator to save on bedding, resulting in wetter bedding and poor health outcomes. Consumption of straw bedding by the cow may also result in inappropriate rumen fill and lower body condition score (5).

Figure 1. Conventional Bedding Pack Barn (BP) for 50 cow herd to over-winter, in Delaware County USA Source; Thurgood J.M. et.al. 2009 (4)

In hotter regions, airflow, solar radiation and ventilation will be an important factor in barn design and management (12).

2.3.2 Free-Stall Barns

Free-stall housing, compared with loose housing, requires the cows to be managed in groups of similar stage of lactation, and offer the advantages of reduced footprint size, (Figure 5), reduced bedding material usage, as well as can offer better health outcomes, especially in hot climates when using sand bedding. These systems are now very common around the world and are generally easier to manage compared to compost bedding systems (6).

The free-stall cubicles are raised above the alleyway, and of a size that suits the largest animal size in the group, and this will depend on cow age and breed (3). The correct fee stall cubicles size, design and bedding is critical (Example in Figure 2), to prevent sideways recumbency, and laying too far forward or back, to ensure cow are comfortable and defecation and urination is into the alleyway, and cows are not stepping on the udders and teats of their neighbours (6). If the cubicles are of the correct design, the cows will prefer to lie in them, rather than in alleyways or loafing areas (Figure 3) (14).

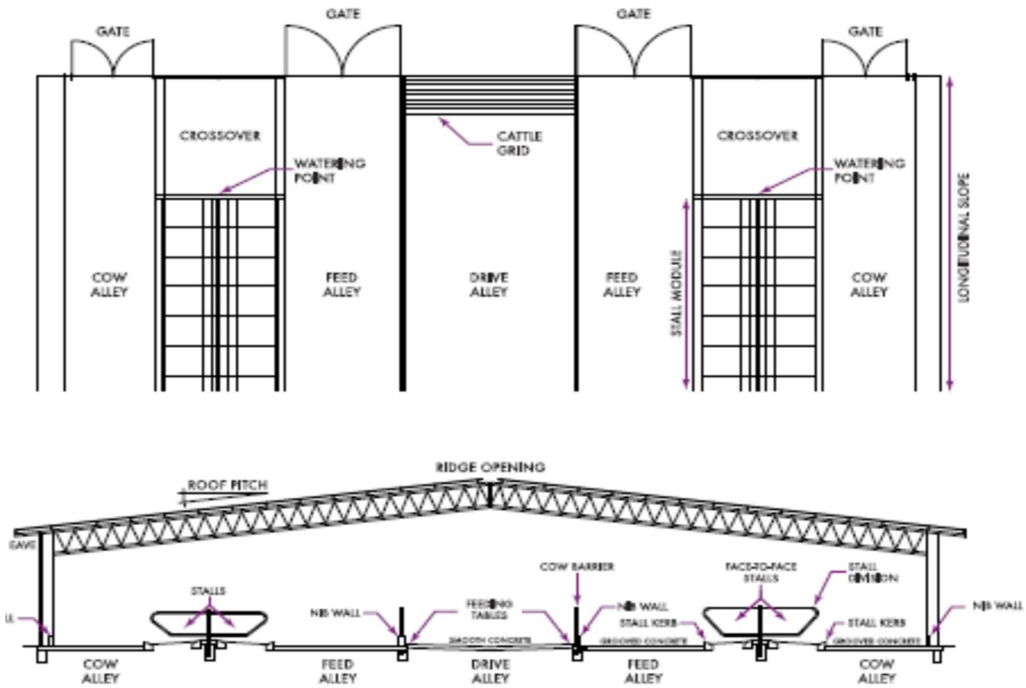

Figure 2. Freestall Design. *Guidelines for Victorian Feed-pads and Free-stalls*. Ed 1. 2010. Vic DPI (21)

Many bedding choices are available for free-stall barns (7). If a mattress or pad is used as the bedding surface, sawdust may be added to improve comfort, absorb moisture, and make cleaning easier (6).

At least 15 cm of bedding is necessary in deep-bedding systems (6) over a cement base. Removal of wet bedding and manure is necessary twice-daily, by manually scraping into the alleyway. Addition of new bedding once or twice a week is also recommended. The alleyways in all housing systems need to be scraped or flushed, at least twice daily (6).

Mats and Mattresses; Rubber mats or soft mattresses are now commonly used around the world, in free-stall barns, with or without sawdust, wood shavings or dried manure solids on their surface.

Organic bedding; Organic materials, including sawdust, chopped straw, wood chips, shredded newspaper, composted or dried separated manure solids, corn stalks, bark, sunflower hulls, rice hulls, peanut hulls have been used extensively as bedding material, both as a top dressing for mattresses or pads and also in deep-bedded stalls. Kiln dried bedding (eg sawdust and shavings) is dryer than green bedding and has a lower potential bacterial content (7).

Recycled manure; Although dried manure solids (DMS) offers good cow comfort, Leach K. A et al (10), reported that there is a lack of scientific evidence on the long-term effects of using dried manure as bedding in the UK, and anecdotal evidence suggests that there is a very high risk of mastitis in humid and wet climates. Husfeldt et al (11) indicated that DMS was being used successfully in free-stalls in Minnesota, and the SCC from these farms was comparable to the state average, although cow health was not assessed.

Inorganic bedding. Buli at al. (8), in their 2010 review, reaffirmed earlier researchers' observations that <u>sand</u>, if managed well is the <u>Gold Standard</u> for free-stall bedding; as it is inorganic and is less conducive to bacterial growth and results in good comfort, as it forms well around the recumbent cow and conducts heat away from the cow. The cow comfort, indicated by longer lying periods, results in less lameness and lower average rumen pH, due to increased time ruminating and increased saliva buffering (8). Sand also provides good traction and cow safety (7), in the stalls as well as in the alleyways, resulting in fewer slippages and injuries, especially when cows are in oestrus.

Sand remains relatively dry on the surface, as milk and urine evaporate quickly, or are drained to lower levels, resulting in lower clinical mastitis and SCC (8). The tendency in the sand bedded free-stall (8) is to use 15-20 cm of sand on top of the stall cement base. It requires refilling with fresh sand every 12-14 days, with additional sand between these days to keep the curb from protruding. American systems (large farms, recycling sand) use 20kg – 25kg of sand / stall/day, which is equal to 7.3ton – 9.1ton /stall/annum to maintain a level of 5cm above the curb. European systems (smaller farms and not recycling sand) use 5kg – 8kg per stall, per day, equivalent to 1.8ton – 2.9ton per stall p/a to maintain a level of the curb (8).

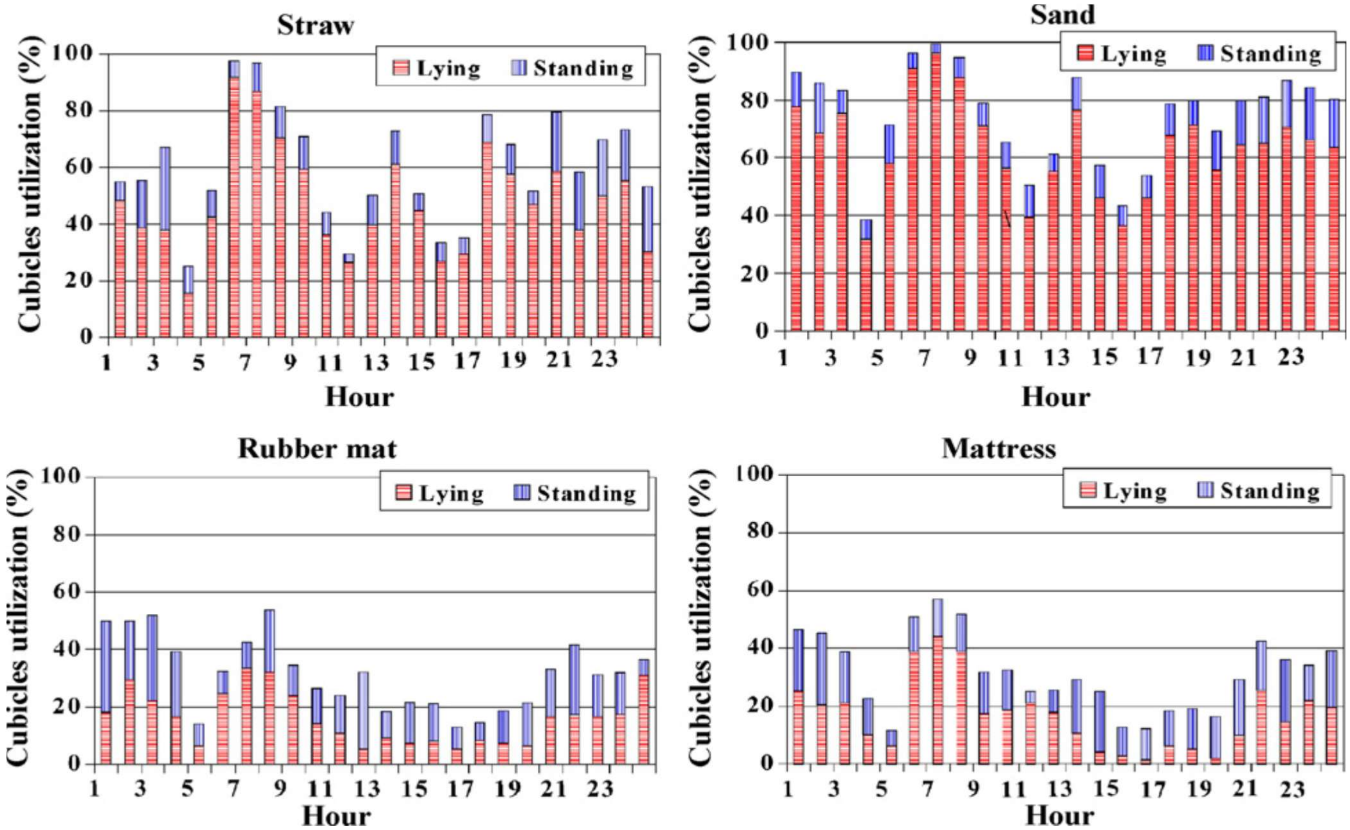

Figure 3. Results of cow freestall bedding preference test. Source: Calamari et al, 2009 (14)

Buli at al. (8), also indicates that <u>sand bedding (in free-stalls) influences cow behaviour in comparison to mats, mattresses and straw (Cows preference shown in Figure 3), in the following ways</u>;

- Cows choice for deep-bedded free-stalls, they prefer sand and straw above mattresses and sawdust;
- Cows on sand have prolonged lying times compared to other materials, resulting in less lameness;
- Better digestion (more rumen buffering) and cow health;
- Cows have more lying bouts and less standing bouts when housed on sand;
- Sand enables cows to express natural behaviour by digging in the sand;
- Adequate lying times decrease the risk of lameness or claw lesions and enables faster recovery;
- Adequate lying times decrease stress;

- Sand makes the concrete in walkways rougher and cows slip less in alleyways. This increases the ability of the animals to express natural behaviour, including oestrous behaviour, increases feeding and drinking times and reduces risk of lameness and claw lesions;

and also has positive influences on production by;

- Increased lying time increases rumination and blood flow to udder, which enhances milk production;
- Increased lying time decreases stress hormone release, which improves overall health and well-being of the cow, and increases production;
- Increased lying time reduces stress on feet, and thus reduces the risk of lameness and claw lesions;
- Increased lying time in combination with soft and cushioned (sand, straw or deep-bedded sawdust) bedding increases recovery from lameness and other health problems, and therefore production;
- The inorganic characteristic of sand reduces risk of mastitis caused by bacteria in the bedding material, and therefore production losses are less compared to other bedding materials.

According to the New York State Cattle Health Assurance Program Fact Sheet 2002 (7), the keys to sand management are to; use washed, screened and graded sand, maintain the sand level at an appropriate depth by adding fresh sand weekly and levelling daily, making sure that stall dividers are correctly mounted as well as providing a settling pit with easy tractor access to remove sand from the main lagoon. However, sand can be recycled by capturing in a simple gravity sand separator then allowing it to stand for 2 weeks, to allow time for any biological material in the sand to decompose, then used to refill the deep bedding free-stalls and not cause mastitis (Personal observation and communication 2018, Indonesia).

Some issues with using sand as bedding include (7); large farms need more equipment and/or more labour to replace sand and clean manure from platform, sand needs to be separated from effluent, equipment wears faster and the sand bedding must be levelled and/or replaced. Australian free-stall and barn design can be found in; *Guidelines for Victorian Feed-pads and free-stalls*. (21)

Figure 4. Cows using sand bedded free stalls with fans (China). Photos: P Chamberlin.

Free-stall barns have a foot print/cow, much lower than compost pack bedding barns (32), and this is illustrated in Figure 5 below.

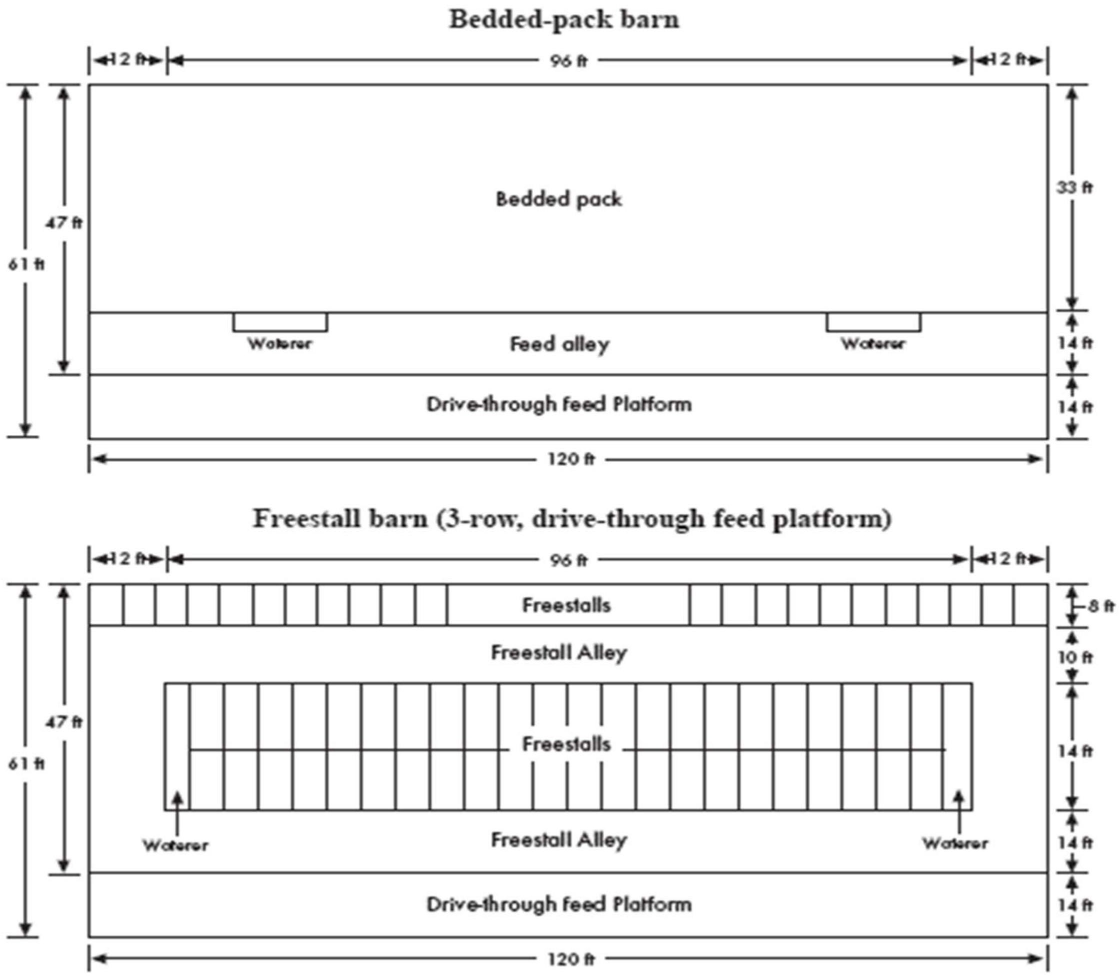

Figure 5. Cow capacity of free-stall (78 cows) and composing bedding barns (39 cows) with the same footprint. Source. Gay, S. W., Bedded-pack Dairy Barns (32)

2.3.3 Composting Bedding Pack Barns

This system is discussed in the next section

3. Compost Pack Bedding (CPB)

This is a loose housing system, has no stalls or partitions, compared to free-stall housing. This increases the cows' resting and exercise areas (3) (24). This combination of resting and exercise space for animals concurrently provides good cow comfort, reduces greenhouse gas emissions and construction cost, compared with free-stall barns and maintains cow health and well-being (22). This design however does require a larger overall footprint, expert pack management as well as more bedding requirements, compared to free-stall housing (3).

The key design difference is that the free-stall areas are replaced with a bedded pack area that is aerated at least twice daily in compost dairy barns (15). The main reasons producers have reported adopting this alternative housing system in the USA, is for improved cow comfort and longevity (15), as well as reduced construction costs and improved heat detection (Bewley 20). Most literature on CPB comes from USA, and some from Holland (22, 23). No scientific literature could be found from Australia on CPB design or operations. Australian literature does exist on dairy barn construction recommendations for feed-pads and free-stall barns (21).

3.1 Principals of composting bedding for dairy cattle confinement

Composting relies on microorganisms, decomposing organic matter, and resulting in CO2, water, and heat. Manure and urine provide the essential nutrients (carbon, nitrogen, moisture, and some microorganisms) for the bacteria to begin and continue the composting process. Composting is an aerobic process, (requiring oxygen), so the bed needs continual aeration, as well as an appropriate balance of oxygen, moisture, temperature, and organic matter (Carbon and nitrogen) (16).

The composting process in cattle barns is not complete but is maintained in a continuous active phase of microbial breakdown of organic matter. In producing compost for the garden, microbial activity is generally finished when the compost is ready to use.

The heat produced by the composting process is absolutely necessary to dry the pack, as well as kill some pathogens, viruses, fly larvae, and weed seeds (16). However, some pathogens remain, and this is discussed later in section 3.6; *Bacteria in CPB*. The pack temperature is used as a guide to the level of microbial activity and the speed of organic matter breakdown and is ideally kept between 45°C to 66°C (16) below the surface, and surface temperatures generally remains close to ambient. Tabara (20) suggests a more practical approach to pack temperature expectations and trying to maintain a temperature range of 40°C – 55°C is sufficient. If the pack temperature is lower than 40°C, the composting process is too slow, and pack temperatures above 66°C will result in bacterial death. Both situations result in the pack becoming inactive and then then too wet (17), from urine and faeces not being broken down.

Pack moisture, from urine and faeces is also critical for microbial activity, and should remain ideally between 45-55%. But an operating range that can still have significant activity for success is 40% and 60% (17). Moisture contents below 40% reduces microbial activity, cooling the compost, and slowing the rate of composting. Moisture levels higher than 55% – 60%, result in the pack becoming anaerobic and slowing microbial decomposition, slowing the composting process (20). The moisture content is easily estimated by squeezing a handful of bedding in the hand. If water can be squeezed out, the pack is too wet, but if you can't form a ball that stays in shape the pack is too dry (17).

A loose and fluffy pack (Figure 15) is an indication that it is working well, especially if it feels warm below the surface, as it is aerated and the microbes are active and generating heat. But if the pack is compacted and cool, resulting in chunky bedding, it is generally not working (composting) well. Bedding material addition requirements and costs are reduced when the composting process it working well (19).

Although more challenging to measure on a practical basis, two other measures are Carbon/Nitrogen ratio (C/N) (ideally between 25:1 to 30:1) and pH (ideally (<7.5 - 8.0). If the N increases, ammonia release may become an issue, and if you can smell ammonia in the barn, the C/N ratio is likely below 25:1 (16). CPB will also have low Greenhouse Gas production potential, especially with smaller pack particle size (< 2cm) and at low pack pH (<7.5). Lower pHs can be maintained with good pack management (20).

3.2 CPB Barn Design and Construction

3.2.1 Composting barn design

Many USA composting pack bedding barns are built by modifying existing designs from two, three, or four-row free-stall barns. Many newly constructed compost bedded-pack barns are built with wooden, steel, or hoop frames with plastic cover. (17).

In the USA, there are two main designs of composting barn designs (15);

- Plastic sheeting temporary structure
- Permanent structures

3.2.2 Temporary composting barns

For example; whoop framed plastic film shelters, covering compost area, with either an outdoor or indoor concrete or gravel feed-pad (15). These have a low construction cost but have the potential issues of allowing solar radiation to penetrate, are possibly difficult to ventilation and are predisposed to storm damage (Personal communication).

Figure 6. Whooped compost barn with external feed-pad Source Endres et al. (15.)

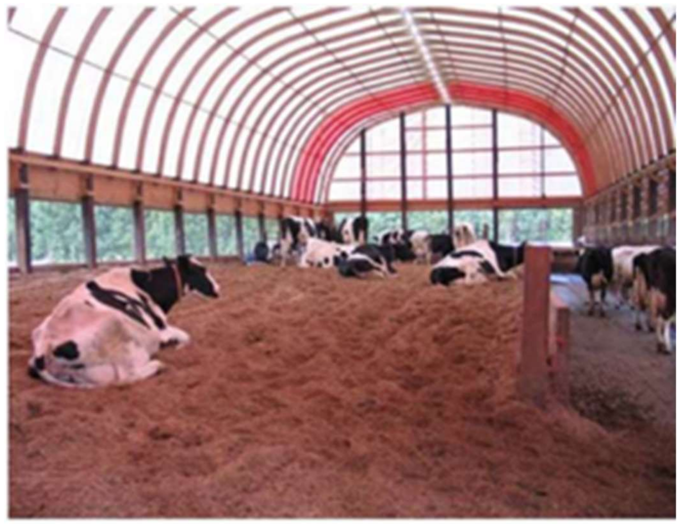

Figure 7. Whooped compost barn, internal feed-pad on RHS. Source Endres et al. (15.)

Figure 8. Composting barn with external feed-bunk and curtain. Source; https://www.pinterest.com.au/pin/650277633668970825/

3.2.3 Permanent composting barns

In the Northern USA, dairy cow compost barns have been developed, which are based on a deep bedding, typically of sawdust or mixed wood shavings and sawdust. To enhance microbial activity the pack is stirred twice daily. While the farmers who are using CPB barns are generally content with cow comfort, cow health longevity and ease of labour chores, their main concern was the limited supply and cost of sawdust bedding material (27). Other advantages of CPB described by producers include; easier and cheaper handling of waste and lower risk of environmental contamination (20)

These are permanent structures with composting resting area, with no watering points (20), with a separate concrete alleyway containing watering points and feed-bunk. A common layout from the University of Minnesota and University of Wisconsin can be seen in Figures 11 and 12. These are generally a single building with sidewall open area and ridge vent width sufficient to allow for proper natural air exchange and ventilation. The single structure usually includes the compost bedded open resting area with a concrete alleyway for access to the feed-bunk and waterers. Some producers have built barns with dimensions to allow for conversion to a free-stall barn in the future by adding concrete alleyways, free-stall platforms, dividers, and waterers (17).

3.2.3.1 Site selection and preparation

Composting bedding material produces additional heat and moisture, in addition to that produced by the cows. To maximize natural ventilation, the barn should be situated to capture prevailing winds and breezes, especially in the hottest season, and be constructed to allow for natural air movement to pass through the barn. An East–West orientation of the long barn axis is preferred to exclude solar radiation drying the pack.

The barn should be elevated to allow water to drain from the site adequately, and not pool on-site and wet the bedding pack. The site should also have a low risk of seepage or runoff of effluent into the environment, including the subsoil. Care should be exercised when excavating/cutting and filling the site, with respect to exposing water draining onto site during wet times, as well as restricting natural airflow (15).

If the bedding pack is well managed, seepage below the pack is usually not an issue, but in any case, the pack base needs to be stable and solid, and can be either clay, gravel or concrete. This will also depend on local building regulations (17).

3.2.3.2 CBP barn structural design criteria

Compost bedding material produces additional heat and moisture to that produced by the cows, therefore the main considerations when designing the barn is to allow and encourage natural ventilation, and provision of efficient artificial ventilation to assist air movement at cow level when necessary (3). In hotter conditions, ventilation is designed to cool cows, as well as to dry the compost pack (17). Side curtains may be necessary, only in cold and windy conditions, especially if rain is driven onto the compost pack.

<u>To maintain adequate ventilation</u>, roof supports need to be 4 – 5 m in height and preferably left open, or at least supply minimum of 3m open wall space (3) around all sides, starting at cow resting height. The sidewall open area target is 0.093m^2/cow in Northern USA (17). Other criteria to be taken into account include roof pitch of barns of less than 4:12 will limit the natural ventilation rate per cow. If the roof is too flat for a wide barn, this limits the natural ventilation rate and makes it easier for pockets of warm moist air to become trapped. This is a greater issue when warm moist air is trapped against cold roof surfaces during winter weather conditions (Stowell et al., 1998) in Northern USA.

Also to be considered, is a continuous ridge vent opening of at least 7.6 cm for every 3.0 m of roof width, with a minimum opening width of 30.5 cm. An East–West orientation is preferred, to prevent solar radiation drying the compost and encouraging the cows to congregate into shaded areas and resulting in compacting and excess moisture in the shaded areas, and over-dry pack areas that receive solar radiation. Prevailing wind direction should also be taken into account when considering orientation, striking a balance between limiting solar radiation entry, possibly using greater roof overhang, and prevailing wind directions entering the barn. Roof overhangs should be no less than 1 m and preferably the distance of one-third of the height of the sidewall (3) to prevent entry of rain (and possibly sun) onto the pack. It is preferable to install gutters to reduce roof runoff from blowing into the pack (17).

Retaining wall; In the USA, a 1.2m high retaining wall is usually built to retain the compost bedding with the roof supports built on top of this wall or erected as an independent structure (15), and another low wall is often installed to separate the bedded- pack from the feed alley. This outer retaining wall may only need to be 80cm high in Australia (Personal communication 2018). Walls designs should also consider the pressure from the manure pack, as well as wheeled equipment exerting pressure on retaining walls. As the compost depth rises, the retaining walls may no longer act as barriers and cow safety becomes a concern (Figure 10). Topping the barrier with wire fencing, steel cable, high-tension wire will eliminate this risk (Figure 9). Wooden fencing should be minimized to avoid negative airflow implications.

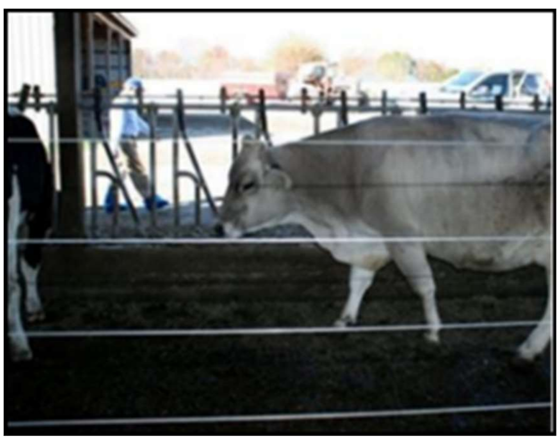

Figure 9. Barrier at edge of pack. Source Ref 17   Figure 10. Pack with no barrier. Source Ref 17

Sidewall curtains help minimize the effects of winter winds and inclement weather on cows and compost temperatures but will not generally be necessary under Australian conditions, especially in the subtropics (Personal communication 2018). Sidewall curtains are generally only necessary to prevent excessive winter wind cooling (in cold climates, eg Northern USA) that increase compost bed moisture evaporation causing bed cooling and heat loss that may not be replaced by compost heat generation. If utilized, sidewall curtains need to maintain a minimum under eave opening of one-half the ridge opening to prevent a barn from becoming a “warm-barn” in winter that results in high levels of condensation, fog, ammonia and cow pneumonia. Tabara (20) indicates that a side wall height opening of 4 – 5 meters around the CPB is preferred.

Compost area required; The recommended bedding area requirements is approximately 10m^2/cow, ranging from 7 to 30 m^2/cow (27). In facilities for special needs cows, producers should provide at least 12 m^2 of resting space.) (Also see 3.4.2 *Stocking density* for further detail).

Walkways from the alleyway onto the pack should be provided every 35-40m to allow easy access to the feed alley and water (27). This will allow cows to spread out on the bedding and reduce the likelihood of fouling the entry points to the bedding pack. Feed bunk space per cow should be 46 to 76 cm (3) with at least 2 water troughs in the feed alley, to decrease moisture on the bedding pack. Water troughs should supply approximately 0.91m of drinking space per 15 to 20 cows (3).

Alleyways, feed-bunks and headstalls are the same design as per free-stalls barns, with the exception that the watering points will be in the cross-overs in the free-stall barns, and in the alleyways in the composting barns

Additional ventilation and light; Provision must be made for additional lighting and mechanical ventilation (3) (See 3.4.3 Ventilation). Any features in the barn need to allow enough head height and width space to allow machines to enter and work at any time of the year (27).

Machinery access; Sidewall provision must be made for access by machines for pack filling and emptying, as well as a system for storing or utilizing the used bedding material. In composting bedding pack barns, faeces and urine are handled as solids, and bedding packs can store manure for 12 months or longer, before cleaning is required (3).

Effluent slurry disposal; If an internal concrete alleyway is constructed, then approximately 25 to 30% of manure and urine is collected on this. A slurry manure handling facility such as a lagoon, must be constructed, or storage with daily manure hauling conducted (27). If this manure is spread back onto the pack, this will increase the amount of bedding needed and may create wet spots on the pack, as well as the extra tractor traffic may compact the pack, reducing composting activity through reduced aeration (27)

3.2.3.3 CBP barn layout

The single composting barn structure includes the compost-bedded open resting area with a concrete alleyway for access to the feed-bunk and waterers.

The bedded-pack is surrounded on all sides by low walls including a wall to separate the bedded pack from the concrete alleyway. (17). (See Figure 11)

This single structure design (by University of Minnesota and University of Wisconsin (15), is illustrated in figures 11 & 12 and can be scaled up

Feed and water alley. For optimum milk production, animal health and reproductive performance, feed and water should be easily accessible and readily available at all times in a feed alleyway. If fed in a separate shed, feed and water intake are often reduced (17).

Concrete feed alleys should be 4.6m wide, with access to the bedded-pack located every 35 – 40m, and at each end. The feed alley, located on one long side of the barn or on both sides of a drive- through feeding barn, allows cows access to feed and water without traveling long distances.

Figure 11. Two CPB housing barns, with concrete alleyway, feed bunk and watering Source.
Source; Left Ref 17, Right https://www.pinterest.com.au/pin/10907224070042659/

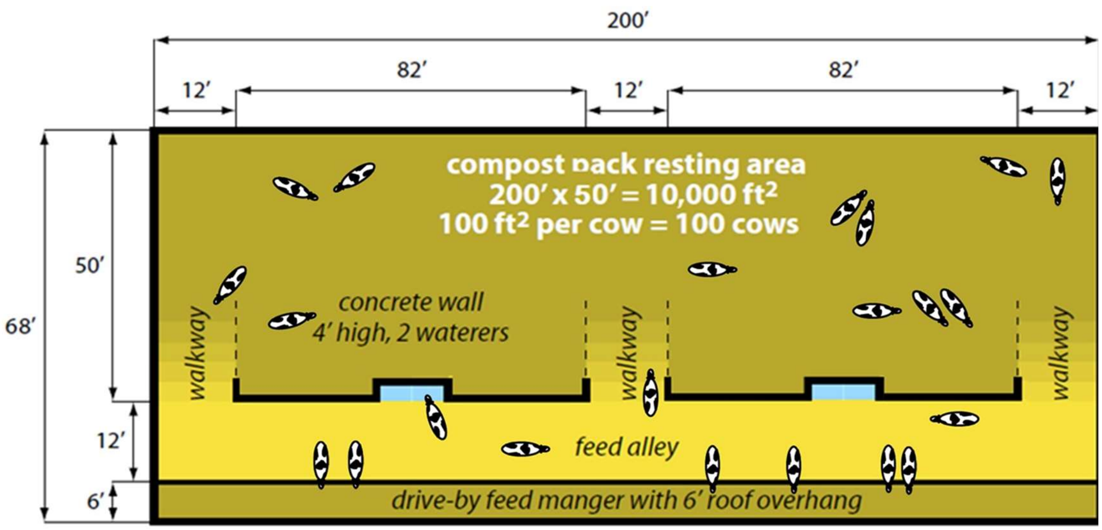

Figure 12; Minnesota type composting barn layout in USA, with concrete alleyway, watering troughs and fed bunk separate from the compost bed. Source; Endres et al. (15)

Figure 13. Centre feed bunk compost barn (15)

Figure 14. Compost darn, bedding pack being tilled (15)

Figure 15. Comfortable cows on compost bedding. Source; *Progressive Dairyman,* 29 September 2017

3.3 Bedding materials for CPB

Most of the published research into bedding material effectiveness has been conducted in the USA. Bedding materials that have been found suitable in Minnesota in 2007, include; sawdust, wood shavings and finely chopped soybean straw (29). Barberg et al, (29) suggest dry, fine wood shavings or sawdust, preferably from pine or other softwoods, as the bedding materials of choice in compost bedded-pack barns (Figure 16).

Sawdust, even when mixed with shavings have enough structure to be able to be easily stirred and remain fluffy enough to assure oxygen transfer within the bedding material (16). In 2013Kentucky dairy producers successfully used green and kiln-dried sawdust, a mixture of shavings and sawdust, a mixture of soy hulls and shavings and a mixture of soy hulls and sawdust (24). The high lignin content of these wood materials provides some resistance to microbial breakdown, which makes it last longer.

Farmers in Israel have successfully used recycled manure solids (RMS) (31) as bedding in compost barns, however when similar trials were conducted in Holland, the dried manure pack proved unsuitable in the moister environment (22). There is little scientific literature from Israel regarding dry manure composting. Klaas and Bjerg (28) however reported that in a trial in Israel, CBP were bedded with wood chips, a combination of sawdust and wood shavings, or dried manure, and all were relatively successful, with no increase in clinical mastitis or SCC when using dried manure solids for compost material.

Sawdust; (Figure 16) The size of bedding particles is particularly important for regulating microbial access to the food source. Saw dust material provides a large surface area to volume ratio (3), is easier to till, and absorbs and holds liquids well. Alternate bedding materials with large particles do not work as well (eg straw) and need to be finely chopped (Figure 18). Sawdust is still the bedding of choice in USA. (17) Kiln-dried sawdust performs well as long as the moisture content is less than 18% on entry to the CPB.

Green sawdust is generally wet and may harbour Klebsiella bacteria and more bedding being required to maintain the composting process.

Wood shavings; (Figure 16) especially when mixed with sawdust, have the potential to improve handling, mixing, aeration, and biological activity due to their large size and ability to maintain air pockets and reduce compaction (27). This increases the ability of microbial populations to grow and break down manure and urine added and prevents excessive compaction of the bedding between tillings (15). Shavings are generally used, as a mix with sawdust, to improve tillability and aeration (27).

Chopped straw: (Figure 18) This is often used to reduce sawdust usage, but care should be taken to ensure straw is chopped very short and is of a non-waxy type and is able to absorb moisture (3). Ideal straw length is < 2cm (20)

Recycled Manure Solids. RSM has shown to be an effective and cheap bedding for a CPB in Israel (28, 31), but requires excellent management and may be unsuitable in climates with a higher relative humidity, due to its ability to promote the growth of pathogenic bacteria when damp (22). Teat preparation must be adequate to provide a control point for the potential transfer of microorganisms from bedding to milk. The detection of zoonotic pathogens in a small proportion of milk samples, independent of bedding type, indicates that pasteurization of milk prior to human consumption remains an important control measure (22).

Soil. Although no literature could be found on using soil as a compost media, the author has observed a few CBP systems working effectively, using soil (eg river flat loam) in a number of sites. This isn't something seen in USA. There is a concern that soil might not provide enough carbon or moisture absorbing capacity and potentially being too moist (Bewley, J. and Taraba, J. 2018, personal communication).

Chipped wood; (Figure 17) Bewley et al., (17) outlined that chipped wood has been found to be less effective than sawdust and shavings due to their low surface area/volume ratio and their tendency to be sharp and cause injury. Wood chipped with blades have smooth surfaces that hold less water than sawn or hammer-milled wood that result in rough surfaces. Wood chipped with flails or hammers may have sharp edges, like toothpicks, that can injure cows. However, Danish researchers found that woodchips were suitable for CPB in Israel (22, 28).

Recycling CPB bedding material; It is possible to allow the composting process to continue and be completed (like garden compost) by stockpiling material after the pack is cleaned out (16). This dry composted material can then be mixed with new sawdust to stretch the sawdust supply for new bedding.

Other bedding materials; Other materials have been successfully used to mix with sawdust and reduce the volume of sawdust needed (17), including; finely processed corncobs, as well as chopped soy straw and chopped flax straw milled through a 20mm screen. However long corn stalk, waste hay, as well as oaten, barley, and wheat straw tend to retain too much water. Wheat straw has a waxy outer surface, making it less absorbable to water or drying. Bewley et al (3) indicated that research is continuing to identify viable alternatives to sawdust or shavings as CPB bedding. Milled peanut and soy hay have a very low C/N ratio and can easily create an ammonia issue, if not managed well (20).

Figure 16. Sawdust (top left) shavings, (right) mixture (bottom left) (Source Ref. 17)

Figure 17. Wood chips produced with sharp (left) and blunt hammer (right) (Source Ref. 17)

Figure 18. Chopped straw (left) and straw run through hammer mill with 3/4" screen (right). Source Bewley et al (Ref. 17)

3.3.1 Unsuitable bedding materials

(3) Course hay and cereal grain straw will mat and clump during cultivation, decreasing the effectiveness as bedding material. Corn stover does not maintain a coarse particle size, decreasing air incorporation (28). Wet or green sawdust may absorb less moisture and more bedding will be required to maintain the CPB and also increased possibility of *Klebsiella* spp. counts in bedding (27, 15). Cedar, black walnut, and cherry were not recommended for CBP bedding because of antimicrobial properties or the potential to cause diseases such as laminitis (27). Sugar cane bagasse was reportedly used on a large farm in SE Asia, and was unsuccessful, due to its very fast degradation, ability to grow bacteria when wet, and often emitted ammonia, possibly due to the high sugar content and low C/N ratio (Personal communication, Vietnam 2018).

Sand and crushed limestone, used for free-stall systems, is unsuitable for use in CPB, as they provide no source of carbon and will not compost, become compacted and are difficult to cultivate (3)

Paper and cardboard absorb a lot of water, but do not retain a structure well when tilled, and do not compost well (16).

Oily and fragrant wood saw dust, shaving and chips may contain antibacterial agents that interfere with the composting process (3).

3.4 Compost bedding pack management

All authors stress that the success of a compost bedded-pack barn hinges largely on how well it is managed (17).

3.4.1 Pack bedding and tilling

Starting the compost pack. To start a CBP, generally a layer of bedding from 25 - 50 cm deep is added (27). The pack soon becomes infused with moisture from faeces, urine and moisture from microbial activity (3). Bedding is added as the moisture content increases, to maintain appropriate moisture level and microbial activity. Moisture content can be easily monitored daily, by taking a handful of bedding and squeezing it. If the ball of bedding falls apart easily, the moisture content is too low (<40%), and microbial activity will be restricted. If no moisture can be extruded when squeezing, and the ball retains its shape, the moisture content is about right (40 – 60%), but if moisture can be extruded from the ball, or the bedding is sticking to the cattle skin and hair, then the moisture content is too high (>55% - 60%), and new bedding needs to be added (17) or some cows removed (3). High moisture content will also restrict microbial activity, as it restricts the microbes' access to oxygen, the temperature will decrease, and the bedding may appear chunky and cool.

In low humidity regions, evaporation is usually greater and the bedding pack will generally remain dryer, with a lower requirement for new bedding material. Israeli researchers found that they often did not need to add much additional recycled manure solids to their CBP, instead relying solely on the composting process to maintain dry bedding (28). Bewley et al. (13) recommended a moisture range of 40% to 60% in the top 15 cm of the pack, and adding new bedding material when the pack moisture is above 55%.

Typically, in USA compost pack bedding barns, a load of fresh dry sawdust (approximately 12 – 20kg/cow/day) is added every 2 to 5 weeks (averaging every 3 weeks) varying by season, weather conditions and cow density (16). Some dairies prefer to add a smaller quantity of new bedding once weekly. Others add a thin layer of bedding every day. Typically, the bedded pack area is cleaned out entirely only once a year and spread on crops as fertilizer. Some producers place the spent bedded material in rows in order to produce finished compost for sale. Some also leave a small amount of bedding in the barn to help initiate microbial activity in the next batch of bedding.

Pack clean out; CBPs are generally totally cleaned out and replace annually. However, Tabara (20) indicates that very well managed packs may be usable for longer periods, for example 2 – 3 years. CPB material can be utilized as fertilizer and soil enhancer, or composted in rows, and recycled as new bedding in a CPB.

Figure 19. Examples of compost-bedded packs of various temperatures. Light and fluffy compost with ideal temperature of 134.6 °F (57°C) is shown at left. Wet and chunky compost with below-optimal temperature 99.6 °F (37.5°C) is shown at right. Source Bewley et al (Ref. 17)

<u>Additives</u> are available that are claimed to encourage bacterial activity in the CPB. Tabara (20) suggests that these additives have questionable effects in well managed packs and should not a used as a substitute for good pack management.

<u>Tilling</u>. It is essential that compost bedded-pack barns are tilled 2 – 3 times daily (24), usually while cows are being milked. This incorporates the urine and manure, and provides aeration which promotes aerobic microbiological activity that result in heating and drying the pack. Tilling also exposes greater pack surface area for drying (28), providing a fresh, dry surface for cattle to lie on. Ideally, the internal temperature for CPB at a depth of 15 to 31 cm ranges from 54°C to 66.0°C (17), although Klaas et al, (28) and Tabara (20) recommends a wider temperature range of 45°C – 65°C). Areas of the barn that are chunky and compacted after stirring indicate pockets of anaerobic activity, usually with higher pack moisture and lower pack temperature (28). This is often the result of cows congregating in one area, adding more moisture and compacting the bedding and restricting bacterial activity.

The depth of tilling varies from 18 to 30 cm depending on the actual pack depth, the specific tillage tool used, and the management style (24). Types of tilling equipment vary from fixed tine tillers, to rotary tillers (Figure 20). Fixed tine tillers generally have a deeper penetration (25 – 30 cm), while rotary tillers develop a finer and more comfortable bed to a depth of (15 – 20cm), (17, 20). Some producers use rotary tillers twice daily, with deeper fixed tine tilling 2 – 3 times weekly (17).

The resulting bedding surface ideally will be at ambient temperature, aerated, fluffy, dry to touch and warm underneath, with no moist chunky areas (3) (Figure 15). Temperatures below the surface will feel hotter to the touch.

It remains unclear if the heat generated from microbial activity causes more heat stress when cows are lying down, but it is assumed that some heat transfer will occur from the pack to the cow when the cow is lying down, possibly adding to heat stress or willingness of cows to lay down during periods higher environmental temperatures. (Bewley J., Personal communication,2018).

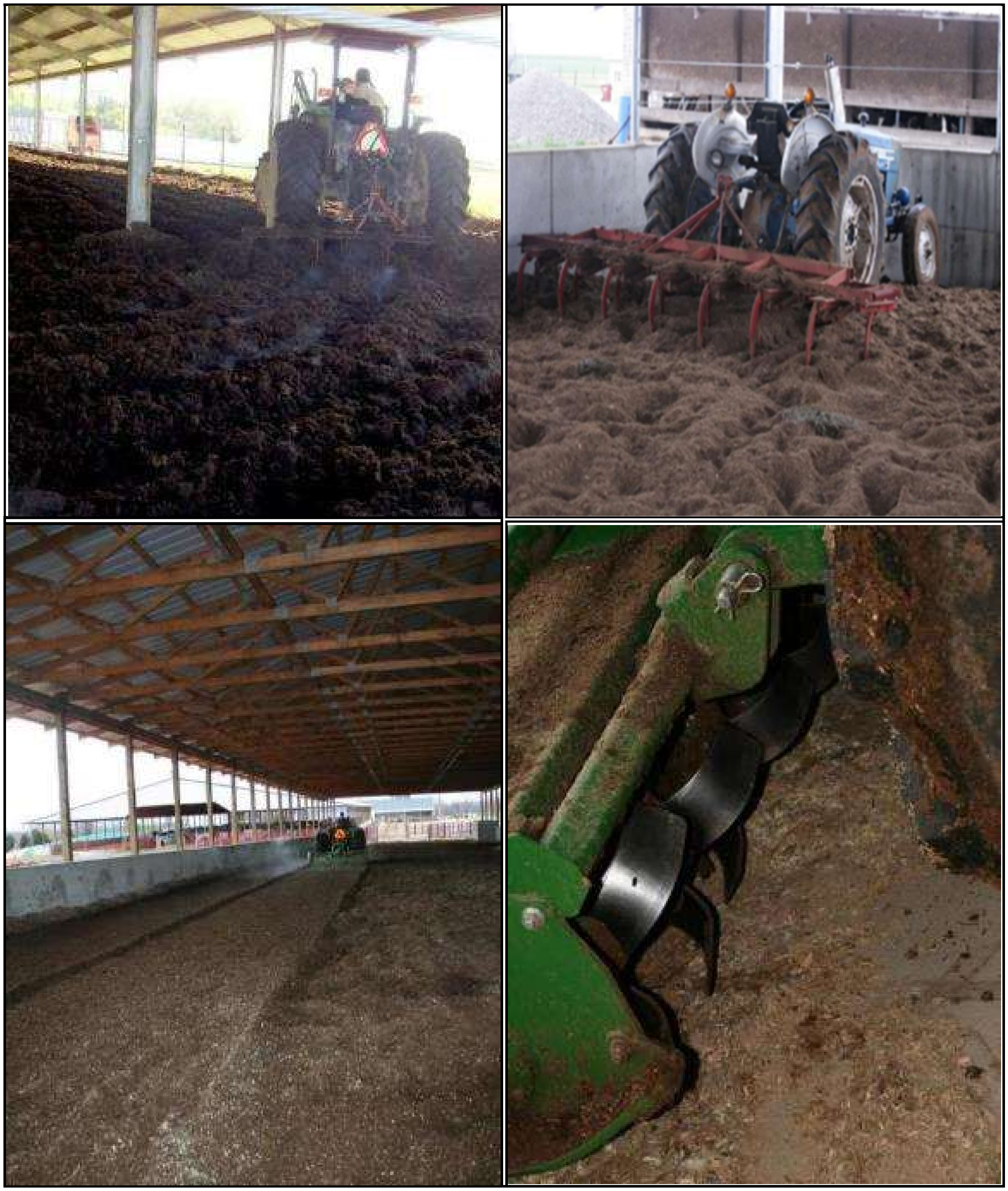

Figure 20. Examples of equipment used to stir compost bedded-pack barns. Source Bewley et al (Ref. 17)

Under Australian conditions, it may be possible to operate what we are calling CPB type systems, partly as deep litter systems, rather than composting systems that are always microbially active, as many will be used on a part time basis, possibly to mitigate heat stress for 4 – 6 hours/day, and cows on pasture at other cooler periods. This will reduce the average daily stocking rate when the barns are utilized, as much of the urine and faeces will be deposited on the pasture, reducing the moisture content of the CPB bedding and the need to replace as much bedding. However, continuous tilling and monitoring is considered to still be essential (Personal communication 2018).

3.4.2 Stocking density

The recommended bedding area requirements range from 7 to 30 m^2/cow (27). If space per cow decreases below approximately 10 m^3 per cow, compaction and moisture could increase, inhibiting compost efficacy (17).

The minimum area of well managed compost required is 9.29 m^2 for Holstein Friesian, and 7.9 m^2 for Jersey. Pack space per cow needs to be increased by 1 m^2 for each 11kg/day of increased milk production above 22kg/day, because these cows will produce more urine and manure as a result of taking in more feed and water. (17). In facilities for special needs cows, producers should provide at least 12 m^2 /cow of resting space.

Tabara (20) suggests that cows producing more than 40 litres/day, require an area of more than 14 m^2/cow for efficient composting to occur. He also suggests that beef units require approximately ½ - 2/3 the area of milking cows.

Dexcel Company NZ (36) recommended the following stocking densities for confined dairy systems based on best practice in New Zealand, Australia and the United States:

- feed-pads 3.5 m^2/cow; 9-12 m^2 if cows spend greater than 12 hrs/day on a feed-pad with access to a loafing area
- if cows will be permanently housed:
    - in loose housing they require at least 11 m^2 per mature dairy cow
    - in a free-stall: one stall and one feeding spacing per cow should be provided

3.4.3 Ventilation and cow cooling

Even the slightest alterations in dairy barn dimensions can have a large impact on air flow. Therefore, careful considerations of ventilation required should be considered in the original design (Also see 3.2.2.2; *Compost barn structural design criteria*) as well as when the barn is in operation. In addition to barn design, producers should also take advantage of proper usage of (depending on local environment) HVLS fans, box fans, evaporative systems (in low humidity) and curtains in both old and new barns to help further improve air flow (12).

Good natural barn ventilation is essential in all barns, and effective artificial ventilation is also essential in most barns (16), to remove cow heat and moisture, as well as the heat and moisture that the biologically active pack generates (15). Ventilation into the barn, should reach a minimum of 4 air exchanges per hour (12). Good air circulation prevents areas of stagnant air developing and the occurrence of hot or cold spots which impact both the compost bed, and the animal comfort. This will also maintain all areas of the compost bedded barn to be equally useful for the cows (16). It is also essential to supply moving fresh air evenly onto the cows, to ensure adequate cooling and access to new air. Without circulation fans in the barn, cows may tend to congregate in areas where natural air flow is higher, especially during heat stress conditions. Petzen et al. (37) reported that cows often congregated in the centre of a barn when temperatures exceeded 27°C.

Congregation of animals in one area leads to excessive manure and urine accumulation and ineffective composting from too high moisture in that pack region. Circulation fans (ceiling or big box) are recommended to help keep the pack dry and ensure adequate air speeds throughout the barn (17). Proper ventilation can improve cows' overall health and immunity by controlling dust and fine particles that may lead to respiratory problems, cooling cows in the summer, and drying the pack surface, which also helps keep cows clean (17).

Many farms have installed high volume/low speed ceiling fans in their compost bedded-pack barns and these appear to work to a varying degree. Evenly distributed air speeds of up to 9.6 km/h at pack level, may increase the length of time the bedding will last in a barn, decreasing bedding and labour costs dramatically (39, 20). When installing fans, it is important to ensure that there is enough clearance for tillage equipment to work underneath them at maximum pack depth.

In the USAV CPB systems, the bedding should also not be exposed to direct solar radiation (3), as this will dry the bedding excessively, and also encourage cows to move to other sections of the barn, effectively increase the stocking rate in the shaded sections.

3.4.4 Maximising ventilation, pack drying and cow cooling

In their research on cow preference of barn design and operations, Selene Reeves et al, (14) indicated that health and financial problems associated with increased moisture, odour, and high temperatures, can all be greatly reduced by improved ventilation in dairy barns. Barn design, including roof design, barn dimensions, proximity of neighbouring barns, and the overall orientation are crucial to maximize natural air flow. The proper use of fans and curtains can further improve ventilation within the barn. Discussed below are specific changes that can be made to improve barn ventilation.

Sidewall curtains; In general, curtains are only used in extremely cold and windy conditions. Curtains used as sidewalls must be adjustable to maximize air flow depending on the season. Curtains should be fully raised in the summer to maximize air flow and care should be taken in winter, to ensure that any restriction of air flow is not sufficient to create condensation, ammonia build up and a humid environment. Curtains should allow an open space at the top of the barn opening one half of the ridge opening width so that air can still flow throughout the barn at a minimum of 4 air exchanges per hour (12).

High-Volume, Low Speed (HVLS) fans (Figure 21) are used to circulate the incoming fresh air thorough all areas of the barn and ensure sufficient barn air exchange is achieved. These fans are named due to their large size (2.5 – 7.3 meter diameter) and slow-moving speeds (45 revolutions per minute for a 7.3 meter fan). For a 7.3 meter HVLS (helicopter) fan, there should be a minimum of 20 meters between each fan if they span down the centre of the barn just over the feed alley. If used correctly, moisture, heat and odour can all be greatly reduced. However, these fans often need the assistance of smaller fans, closer to the pack, to establish sufficient airspeed to dry the pack and cool the cows (12).

Figure 21. High Volume Low Speed fans in a free-stall barn with open sides (Source P Chamberlain, India)

Box Fans (Figure 22), are smaller than HVLS fans and provide improved air movement at cow and pack level, to dry the pack and cool the cow. Commonly, these fans can range from 0.9 meter to 1.3 meter and, therefore, should be spaced 10 meters for 0.9 meter fans, and 15 meters apart for 1.3 meter fans, and at an angle that is below the downstream of the preceding fan. These fans may also oscillate. The larger the fan, the more space can be placed between each of them. Fan placement should be focused over the cow beds and feed lanes (12).

Tabara (20) indicated that in warm and humid regions, barn ventilation and continuous fan forced air are essential for cow cooling and pack moisture evaporation.

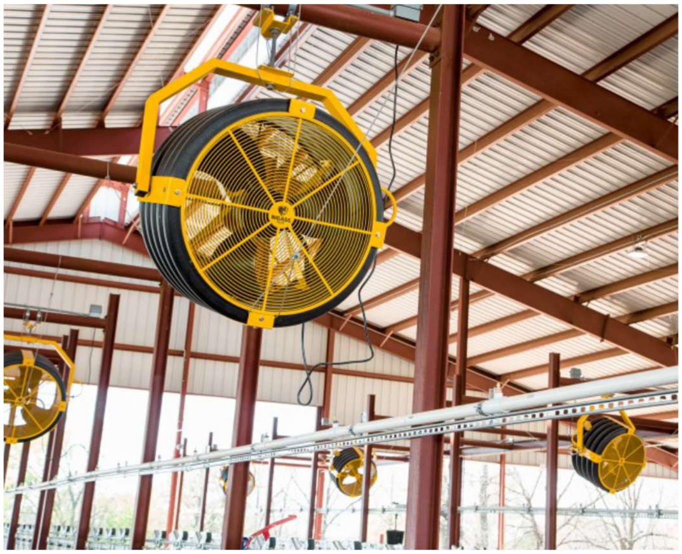


Figure 22. Oscillating box fans directing air down onto cows and bedding area. Source (Left Ref 12. Right P Chamberlain, India)

Tunnel barn ventilation (Figure 23) systems are also an option to ventilate barns, but are expensive to run (Personal observations and communications 2018). These barns have closed sides and draw large volumes of air out of the barn from one end.


Figure 23. Tunnel free-stall dairy barns with extraction fans and clear plastic walls (Source P Chamberlain, Indonesia)

Evaporative airflow (fogging) systems; these systems move high volumes of air and water mist onto the cows (Figure 24). They rely on the principal of cooling the air through evaporation, and only work in low humidity regions, and are counterproductive in moister climates, as they increase humidity (42).

Figure 24. Fogging (mist) cooling system in Israel. Source Arbel, Ref 42.

Air flow from all fans can be reduced due to poor maintenance, especially dust build-up. Therefore, upkeep is necessary. Fan blades and grills should be cleaned to be free of dirt and dust. Regular oiling, realignment, tightening of the fan belts, and the replacement of damaged fans should all be completed before each summer season (12).

Spraying cows with water; Under hot and humid climatic conditions, cows can be cooled effectively in spray areas, where water is sprayed onto cows to make them wet, then fans move air around the cows (43). These are often at the feed bunk or collecting yard to the milking parlour, or can be special yards, close to the cow barns. These are commonly used in SE Asia to cool cows (Personal communication).

Figure 25. Cows being sprayed with water in holding yard prior to milking (P Chamberlain Indonesia)

Automatic Fan Control. Fan operation can be linked to ambient temperature and humidity, however recent information suggests that continuous fan use is necessary for CPB systems under most condition in the US, and especially under hot and humid conditions (20)

Additional lighting may be used in the barns (3).

3.4.5 CPB pack management summary (Summary from above information)

- Ensure ventilation is appropriate and exogenous water does not enter pack (eg rain or water from water troughs or sprays) to wet the pack
- Ensure bedding material is suitable for composting
- Ensure air flow into the shed is sufficient, especially if using side curtains
- Ensure fans are working effectively and air movement at the cow and pack level is sufficient
- Till the pack twice daily
- Monitor daily for moisture, temperature, evenness of cow distribution, bedding pack consistency, smell at pack level (for ammonia), cow cleanliness, cow rumination and laying behaviour
- Act quickly to address pack moisture and temperature concerns (add new bedding, reduce stocking rate, address cow congregation issues)
- Implement and maintain appropriate mastitis and milking management program, to reduce the risk of organisms from the pack causing increased cases of clinical mastitis, increased SCC and increased milk contamination

3.5 Common limitations and pitfalls in CPB systems (summary from above)

- The primary limitation for compost-bedded pack barns in USA to date has been sawdust availability and price (20). These barns require three to four times the amount of bedding of a typical free-stall barn. In on-farm experiments, so far alternative materials have not performed as well as sawdust (3).
- Poor barn/shed construction/conversion, with poor ventilation, resulting in slow air exchange, higher ammonia levels, heat stress, respiratory conditions, etc

- Increasing cattle numbers and reducing area/cow below 10 m^2 per cow, resulting in pack compaction and increased moisture content, inhibiting compost efficacy (17) and resulting wet areas increasing the risk of higher hygiene scores and mastitis. Tabara (20) reports that cows producing 40 litres/day and above, really need an area above 14m^2/head, for efficient compost pack function.
- Poor artificial ventilation resulting in low air speed at pack level, poor pack drying, wet packs, dirty cows, higher levels of clinical mastitis, SCC, lameness and other animal health and production issues.
- Inappropriate bedding, for example; 1. chopped wheat straw – resulting in poor water absorption and wet packs, 2. long straw resulting in uneven tillage and patchy pack performance
- Solar radiation drying sections of the pack resulting in uneven pack performance and uneven cow distribution
- Uneven use of the pack by cows, with aggregation of cows in certain areas, due to inappropriate and patchy air quality, air temperature, air humidity, inadvertent water entry to the pack, pack comfort and too few entrances to the pack, resulting in crowding on entry/exit
- Inadequate monitoring of pack moisture and temperature
- Changes being made to late or too slowly (eg in altering cow numbers, adding new bedding, improving/changing fan use etc)
- Inappropriate monitoring of cow comfort and behaviour, including distribution, respiration, laying behaviour, cleanliness, rumination, gait, etc
- Lack of understanding of cost and availability of bedding, especially sawdust
- Lack of understanding of the risk of potential bacterial contamination and growth in the pack, and the subsequent potential for adverse health effects in the cow, especially with suboptimal pack observation and management

3.6 Bacteria in CPB

It is becoming evident from recent work, that the original assumption that the composting process will eliminate mastitis-causing organisms is incorrect and that ambient temperature has a strong influence on the presence of mastitis-causing organisms on CPB bedding (39). Petzen et al. (37) indicated that managing for good composting allowed proliferation of coliforms, staphylococci, streptococci, and bacilli species in the pack. Although bacterial levels were high, the expected effects on SCC, bulk-tank SCC, and clinical mastitis have not been established (30). However, many large compost pack barn systems in the tropics have converted to sand bedded free-stall systems, due to very high levels of clinical mastitis (Personal communication with personnel at large SE Asian dairy operation, 2018)

Higher temperatures promote pathogen destruction, which may be advantageous for mastitis-causing bacteria destruction. However, temperatures observed by Black et al. (24) did not reach the level necessary for bedding sanitization. The lack of material sanitization during the microbial processes in the CBP indicates that the system is more of a semi-composting system that does not fully cycle through the entire composting process.

These temperatures, although not high enough to eliminate the organisms, are indeed necessary in CPB systems to increase moisture evaporation to reduce moisture from manure and urine. The CBP should remain between 40 to 60% moisture for efficient composting (27). C/N ratios also influence growth of some bacteria, and a low C/N ratio (<25:1) result in ammonia production and depend mainly on the type of bedding material used.

Black, et al (33) also reported that the temperatures reached in composting packs were generally not high enough to eliminate mastitis-causing bacteria, and many other parameters also affect the level of bacteria in CPB, including ambient temperature, C/N ratio, stocking rate. Specifically;

- Coliforms; CBP temperature, CBP moisture, space per cow and C/N ration had no effect on coliform counts. Escherichia coli reached a peak concentration when the C/N ratio was between 30:1 and 35:1 (ideal C/N ratio is between 25:1 to 30:1 (16))
- Staphylococci counts increased mainly as ambient temperature increased.
- Streptococci counts decreased with decreased stocking rate and increased composite temperature and increased with increasing ambient temperature and moisture. Streptococci counts peaked at a C/N ratio ranging from 16:1 to 18:1.
- Bacillus spp. counts were reduced with increasing moisture, C/N ratio, and ambient temperature.

Mastitis-causing bacteria thrive in similar conditions to that of composting bacteria and microbes, making elimination of these at higher temperatures (55 to 65°C) difficult in an active composting environment. Producers must use recommended milking procedures and other preventative practices to maintain low somatic cell count in herds with a CBP barn (24). Bewley (20) recommends Coliform mastitis vaccination for all cows in CPB systems.

Researcher have also discovered that Barn Temperature (BT) has an important influence on bacterial growth in CPB and that CPB may be more difficult to manage in warmer environments. Eckelkamp et al (39), found that compost internal temperature increased with increasing maximum barn temperature (BT), compost moisture content decreased with increasing BT and herd hygiene score decreased with increasing BT and increased with increasing compost moisture content. Herd SCC increased with increasing BT but were unaffected by compost measurements. As compost internal temperature increased, staphylococci, streptococci, and bacilli species growth in the pack are decreased and coliform species growth increased. Low CBP moisture and high CBP temperature reduced bacterial levels. Cow hygiene and udder health indicators had a stronger relationship with BT than with CBP internal temperature and moisture.

These indicate that a higher BT has a positive effect on composting activity and cow hygiene scores, however has a negative effect on SCC and coliform growth and will also increase heat stress on cows (39).

There is a lack of published literature and data about CPB in the tropics, however many large systems in SE Asia are now converting to free-stalls due to high levels of mastitis. It is unknown how much of the poor outcomes is due to lack of appropriate management and how much is due to climate (Personal communication 2018).

3.7 Capital and Operational Costs

In a US study, Endres et al (15), found that CPB barn building costs ranged from USD \$33,000 to USD \$300,000, with a cost per cow ranging from USD \$625 to USD \$1,750 (barn only, does not include milking parlour). The building costs ranged widely depending on the amount of on-farm labour was utilized and amenities added to the barn.

Bedding material costs ranged from USD \$0.35 to USD \$0.85 per cow per day, depending on the source of sawdust and from how far it had to be transported to reach the dairy. Bedding costs and availability of bedding materials was by far the major concern expressed by the producers.

They also noted that appropriate ventilation can drastically reduce bedding costs ventilation, and that fan speeds of 9.6 km/h may increase the length of time bedding will last in a barn, decreasing bedding costs by USD $11,800 per year (39). Decreasing space per cow below 8.6 m² resulted in a drastic increase in bedding load requirement for all bedding types (39).

With respect to cost of bedding, Eckelkamp (39) reported that kiln-dried bedding under all analysis was the best option for both cost and load amount, even when the cost of a load of bedding was > $300 for kiln-dried bedding (73.58 m^3 per load). However, green bedding with a moisture content of 30% was similar or lower in cost to kiln-dried bedding, with a moisture content of 12 - 18% moisture. Having the fans on, irrespective of THI, increased bedding life and decreased bedding costs for both green and kiln dried bedding. Similarly, maintaining 20 cm of bedding with internal temperatures ≥ 37.8°C decreased bedding costs and increased bedding life for both green and kiln-dried bedding. (39).

3.8 Outcomes and welfare considerations

It should be pointed out that all of the positive outcomes below have been reported from Northern USA.

Most USA dairy producers report that the main reasons for considering building CPB are cow comfort and dairy cow longevity (16) as well as lower construction costs and lower risk of environmental contamination (20). They also report better heat detection and pregnancy rates. (15, 20). Public perception of CPB barns is very good, and cow welfare in these systems is seen by the public as being better than other housing systems (22). There are also reports of less odours and lower fly populations with well managed CPB (20)

Dairy cattle housed in CPB barns had reduced lameness and hock lesions compared with those housed in free-stall barns and had no adverse associations with body condition, respiration rates, mastitis prevalence, culling, or mortality. CPB barns had better feet and leg health, compared to free-stall barns, as indicated by the reduced lameness and hock lesion prevalence, (25). Heat detection was also increased in CPB systems (15)

Productivity. From their study of The Dairy Herd Improvement Authority figures in Minnesota USA in 2008, Endres et al (15), reported that when moving their cows from the previous housing system to the compost barn, 89% of the dairies had a significant increase in milk production (averaging over 900kg/year). Udder health and milk quality were not necessarily compromised when housing cows in CPB systems, with 67% of the dairies having a reduction in mastitis infections. Additionally, 57% of the dairies had an increase in heat detection rates (36.9% before and 41.5% after change in housing) and 71% of the dairies had an increase in pregnancy rates (13.2% before and 16.5% after change in housing). Herd turnover rates averaged 25.4% before and 20.9% after the change in housing.

Cow health and welfare. Enderes et al., 2008 (15), reported that cow feet and leg health were good in the compost barns visited. The average prevalence of lameness in compost dairy barns was much lower than the 27.8% reported by Cook's (40) recently reported prevalence in free-stall barns; and the 19.6% observed in tie-stall herds (40). Overall, 25.1% of cows exhibited a hock lesion, with 24.1% having hair loss and 1.0% having a swollen hock in CPB barns. Seven of the 12 herds had no severe hock lesions. Furthermore, Endres et at. observed in free-stall herds (n = 5,328 cows) that 14.1% of cows housed on mattress-based free-stalls and 1.8% of cows on sand-based free-stalls had swollen hocks.

Results on the prevalence of lameness and hock lesions in Enderes's study suggest that cow welfare, especially in relation to feet and legs, could potentially be better in CPB barns than in free-stall systems. There were however some concerns about dust, which could predispose cows to pneumonia or cause eye irritation, and air quality, such as ammonia and/or hydrogen sulphide levels, and they indicated more research is needed in these areas.

Hygiene scores for cows housed on compost barns were similar to those housed on waterbeds in free-stalls and lower than those for cows housed in sand free-stall or rubber-filled mattresses (39). Reneau et al, proved a positive correlation between Hygiene Scores (1 - clean to 5 – dirty) and level SCC, indicating that the cleaner cows in CBP had lower SCCs.

3.9 Conclusions

Eckelkamp (39) concluded that, *when managed according to recommendations, compost bedded pack barns improved lameness, hock health, reduced SCC, maintained cow cleanliness, and increased milk production when compared to free-stalls and to state averages* (30).

Janni et al, (27) concluded that; *good management is the key to the success of compost dairy systems. They require excellent pack and ventilation management; appropriate stocking rates and bedding use; and excellent cow preparation procedures at milking time. The bedded pack needs to be aerated twice daily to refresh the surface and enhance microbial activity in the pack*.

Enderes et al (15) concluded that, *based on current observations in USA, compost dairy barns can be an adequate housing system for lactating dairy cows, especially for small to medium size dairies, or as a special needs barn in larger free-stall dairies. Like any system, optimum management is absolutely necessary to achieve desirable results. There are many housing options for dairy cattle, and one should choose the option that will work best for them*.

These systems have been proven to be workable in the Northern USA states, only with extremely good management systems in place. The economic viability is now being questioned with changes to the cost and availability of sawdust.

There have been serious problems recorded using these systems on a large scale in tropical SE Asia, but there is a lack of data and published evidence of the reasons for failure, either being management, design or operational issues. (Personal communication 2018). In light of this lack of data, care needs to be exercised if constructing CPB barns in Australia. Also, more work needs to be done on bedding material (3) that is suitable, available and economically viable in Australia. There will also not be a single system that suits all farming areas and management styles in Australia, and each farm will need to get good advice and tailor a system to suit their needs and environment. It is also probably advisable to have a company, experienced in the design and construction of these systems in Australia, advise on the design and construction of an individual system, as well as developing a design that can be modified into a free-stall system in the future, if the CPB is not viable (16).

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