Compost Bedded Loose Housing (CBP) Dairy Barn for Sustainable Dairy Production

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### Compost Barn Research Team

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<thead>
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**Funding:** University of Kentucky; USDA-NRCS CIG; KY-NRCS-CIG; Kentucky Governor's Office for Agricultural Policy; USDA-SERA; USDA-FAS
CBP barns fit within goals of sustainable agriculture

- **Benefits to the cow**
  - Space,
  - health,
  - rest,
  - exercise,
  - social interaction

- **Benefits to the farmer**
  - low investment,
  - labor-intensive,
  - reduced manure storage costs,
  - milk production (milk quality, milk yield, conception rate),

- **Benefits to the environment**
  - reduced ammonia and greenhouse gas emissions, odor and dust emissions,
  - reduced energy consumption,
  - improved manure fertility flexibility to meet nutrient management plans).
Goals

- Reduced air and water pollution
- Composting process - Compost bed
- Greenhouse gasses
- Barn Structural impacts - ventilation
- Bed management - bedding and tillage
- Fertility of compost
Environmental Impacts
Bedding Impact On Waste System

Compared to freestall barn using sand bedding – “the gold standard”:

- Less capital spent for recovery and recycling sand
- Less time and $$ for storage desludging
- Less equipment wear from sand abrasion
Compost bedded barn with drive thru feed alley

Storage pond with up to 2/3 less manure entering
Important alternative manure management practice to allow flexibility in utilization of plant nutrients and organic matter for soil fertility.
Composting Process
Compost Dairy Barn
The “Ideal” Composting Process

```
Compost Pile
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- Carbon
- Nitrogen
- Inorganics
- Water
- Microorganisms

**Inputs:**
- Water
- Heat
- Oxygen ($O_2$)

**Outputs:**
- Ammonia ($NH_3$)
- Nitrous Oxide ($N_2O$)
- Carbon Dioxide ($CO_2$)

**Final Output:**
- Organic Matter
- Inorganics
- Microorganisms
Temperature Dynamics

Adding feces, urine and bedding continuously changes static bed composting process.

![Temperature Dynamics Graph](image)

- **A**: mesophilic
- **B**: thermophilic
- **C**: mesophilic
- **D**: maturation
Compost Bedded Pack

- Aerobic Zone
- Aerobic/Anaerobic Transition Zone
- Anaerobic Zone

Depth of Compost Bed:
- 60 - 120 cm
- 25 - 30 cm

Ambient Temp, °C

50 - 60 °C

Soil
For Equal Heat Loss Surface Areas:

<table>
<thead>
<tr>
<th>Heat Loss to Air Surface Area (sq. m)</th>
<th>Heat Generation Volume (cu m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost Windrow Aerobic Zone</td>
<td>1.6</td>
</tr>
<tr>
<td>Compost Bed Aerobic Zone (20 cm depth)</td>
<td>6.1</td>
</tr>
<tr>
<td>Compost Bed Aerobic Zone (30 cm depth)</td>
<td>4.1</td>
</tr>
</tbody>
</table>
GHGs and Dairy Manure

(Amon et al., 2001)
Limited GHG Measurements

CBP Barn Free Air Space Concentrations (ppm)

- Ambient
- Pack Srfc
- 6” deep
- 12” deep
- 30” deep

CBP Barn Free Air Space Concentration (ppm)

- Ambient
- Pack Srfc
- 6” deep
- 12” deep
- 30” deep

Graphs showing concentration levels at different depths.
What Was Learned of Constructed Compost Barns
Heat and Moisture Concerns in Compost Barn
Structural Components Affecting Ventilation Rate

- Orientation
- Position within landscape
- Nearby obstructions upwind and downwind
- Side wall opening height
- Side wall opening area
- Roof elevation
- Roof slope
- Ridge opening width
- Ridge opening design
Orientation - Wind

Summer Winds

South
Orientation - Sunlight

- East-west orientation has least sunlight penetration over north - south
Roof Pitch and Style

- Under calm winds, a gable roof has 3.5 times higher ventilation rate than a monoslope roof (shed roof)

- Under calm winds, the 5/12 pitch gable roof had a 35% higher ventilation rate than the 3/12 pitch gable roof

  - For the same structure width, a higher pitch roof ridge vent has higher elevation over inlet that increases buoyancy
Side Wall Opening

- Under calm winds, higher side wall opening gave higher ventilation rate.
- In winds, if opening increased from 1.8 m to 3 m ventilation rate increased by 60%.
Circulation/Cooling Fans

- **Two types fans:**
  - HVLS ceiling fans for air speeds at cow level of 2 m/s
  - Box/Panel fans for air speeds of 4 m/s

- **Fan spacing**
  - 2.5 times HLVS fan diameter
  - 8-10 times box/panel fan diameter
### Potential Warm Weather Compost Bed Drying Rate

- Rototilled bed (~ 55% wb) – Cows Producing 23 kg/day

<table>
<thead>
<tr>
<th>Air Velocity 2” Above Bed Surface</th>
<th>Net Water Drying Rate</th>
<th>Cow water output</th>
</tr>
</thead>
<tbody>
<tr>
<td>mph</td>
<td>ft/min</td>
<td>#/ft²/day</td>
</tr>
<tr>
<td>4</td>
<td>360</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>180</td>
<td>0.6</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0.2</td>
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</table>
Ridge Vent - Opening

- In calm winds, barn ventilation rate increases 2.5 times if ridge opening is increased from 1.7 cm/m building width to 4.2 cm/m.
- Under windy conditions, an open ridge of 2.5 cm/m of barn width will increase the barn ventilation rate by 33% over 1.7 cm/m.
## Ridge Design

<table>
<thead>
<tr>
<th>Type</th>
<th>Name</th>
<th>Recommended Count</th>
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</thead>
<tbody>
<tr>
<td>[Image] Open Ridge</td>
<td>Open Ridge</td>
<td></td>
</tr>
<tr>
<td>[Image] Open Ridge with cover</td>
<td>Open ridge with cover</td>
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<tr>
<td>[Image] Overshot</td>
<td>Overshot</td>
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<tr>
<td>[Image] Hoop structure</td>
<td>Hoop structure</td>
<td></td>
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<tr>
<td>[Image] Capped ridge</td>
<td>Capped ridge</td>
<td></td>
</tr>
</tbody>
</table>

![Pie Chart]

- Open ridge (n=6) 14%
- Open ridge with cover (n=8) 18%
- Hoop structure (n=2) 5%
- Capped ridge (n=25) 58%

**Barns = 43**
Potential Design Flaws

- Not enough space per cow
- Inadequate ventilation
  - Sidewall opening above retaining wall too low (<3.5 m)
  - Too close to other buildings (>25 m)
  - Too small ridge opening (<4.2 cm/m of width)
  - Poor ridge opening design
  - Fan availability/placement
- Walls along pack
- Proximity to feed
- Lack of eave overhangs (1/3 side wall height or curtains to block rain and cold wind)
- Building orientation
- Alleyways <4.25 m
- Not enough feed bunk space (60 to 75 cm per cow)
- Not enough water space (60 cm of tank perimeter per 15 to 20 cows)
- Cow flow/traffic bottlenecks
- Waterers access from pack
- Concrete base?
- Access to alleyway from pack limited (access spacing <3.5 m)
- No fence on top of knee walls
Potential Design Flaws Cause

Grouping/Crowding of Cows in Heat Stress
Managing the Compost Bed
Stirring the Bed

2 x per day religiously

Rototiller tillage depth 15-20 cm

25-30 cm stirring depth with deep tillage
Hybrid Tillage/Aeration Tool
Average Water Holding Capacity = 72.7%
Pack Moisture Control

**MOST IMPORTANT MANAGEMENT FACTOR**

- Biological activity generates heat which helps to dry the bedding material
- Bedding cannot absorb all the water from urine and manure without evaporation of water
- Too wet of a bedded pack reduces aeration, slows biological activity, slow heat generation and water evaporation

*Unless area per cow more than doubles in winter/wet season*
Bed Drying Rate during a Year
- Using 30 year weather means -
Potential Bed Failure

Dense Beds

Poor Hygiene
Average Bed Moisture Content Effects on Average Bed Temperature

Average Bed Temperature at 8" depth (F)

Average Bed Moisture Content (% wb)

- ● Fall Average Bed Temperature 8" Deep (F)
- ○ Winter Average Bed Temperature 8" Deep (F)

Optimum Moisture

Moisture Management Range

Fall Average Bed Temperature 8" Deep (F) and Winter Average Bed Temperature 8" Deep (F) vary with average bed moisture content. The graph shows a peak in temperature at an average moisture content, indicating an optimum moisture level for temperature maintenance. Lower and higher moisture contents result in lower average bed temperature.
Type Bedding Materials

Sawdust

Sawdust/Shavings

A

B

C

Shavings
1:1 Ground Straw:sawdust

Ground Straw thru 2 cm Screen

Chopped Straw
Sweep tillage tool

Rototiller tillage
Particle Size and pH Affect GHG Production

![Graph showing the effect of particle size and pH on GHG production.](image-url)
Compost Fertility
The highest fertility values are reflected around 50-60% fraction of the profile.
Lower moisture contents tend to experience lower C:N ratios.
## Change in Soil Test Phosphorus

### Faywood silt loam soil

<table>
<thead>
<tr>
<th>Time (Days)</th>
<th>Control STP (mg kg⁻¹)</th>
<th>Application Rate (mg kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>0</td>
<td>18&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
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<td>18&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>120</td>
<td>16&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19&lt;sup&gt;bc&lt;/sup&gt;</td>
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\* NS =; not a significant change from the control; α=.05.

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### Low STP

### High STP
Study Implications

- In general, CBP yields more plant available P than fresh manure
- STP measurements likely change within a growing season
- Long Term Fertility
- Contradicts results of limited current literature

Limitations:
- Ideal conditions in the laboratory
- One soil type used
- No competition for available P
- Incorporated material only
- Highly processed samples
Questions?
Soil Aggregate Microenvironment Model

Distribution of physiological properties within an aggregate/particle. Lines represent isobars of $O_2$ concentration (%). Coyne, 2010.

Typical Soil Aggregate