Manure Management: Processing, Storage, and Land Application

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MREC 58th Annual Rural Energy Conference Workshop

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Associate Professor and Extension Specialist
Farmstead Sustainability

- Feed storage
- Crops
- Livestock
- Manure
- Processing
- Manure storage
Manure Systems

Collection

Manure Production and Collection

Processing/Treatment

Sand Removal

Solid Removal

Solid Storage

Liquid Storage

Storage

Digestion

Advanced Treatment

Transfer and Land Application

Manure Transfer and Application
Survey results: Manure management practices

Larger farms handle liquid manure and smaller farms handle solid manure

<table>
<thead>
<tr>
<th>Milk per cow per lactation (kg)</th>
<th>4,789</th>
<th>7,982</th>
<th>11,174</th>
<th>14,367</th>
<th>17,560</th>
<th>20,752</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk (kg/cow/day)</td>
<td>15</td>
<td>25</td>
<td>35</td>
<td>45</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>DMI (kg/cow/day)</td>
<td>19</td>
<td>22</td>
<td>24</td>
<td>27</td>
<td>30</td>
<td>33</td>
</tr>
<tr>
<td>Feed Efficiency</td>
<td>0.80</td>
<td>1.15</td>
<td>1.42</td>
<td>1.64</td>
<td>1.82</td>
<td>1.96</td>
</tr>
<tr>
<td>Manure Output (kg/cow/day)</td>
<td>53</td>
<td>59</td>
<td>66</td>
<td>72</td>
<td>78</td>
<td>85</td>
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<tr>
<td>kg Manure per kg Milk</td>
<td>3.5</td>
<td>2.4</td>
<td>1.9</td>
<td>1.6</td>
<td>1.4</td>
<td>1.3</td>
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</tbody>
</table>

Shaver, Midwest Manure Summit, 2017
## Manure Nutrient Output

<table>
<thead>
<tr>
<th>Milk per cow per lactation (kg)</th>
<th>4,789</th>
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<td>25</td>
<td>35</td>
<td>45</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>N Excretion (kg/cow/day)</td>
<td>0.34</td>
<td>0.39</td>
<td>0.43</td>
<td>0.47</td>
<td>0.51</td>
<td>0.56</td>
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<tr>
<td>N Excretion (kg) per unit milk (kg)</td>
<td>0.023</td>
<td>0.016</td>
<td>0.012</td>
<td>0.011</td>
<td>0.009</td>
<td>0.009</td>
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<tr>
<td>P Excretion (grams/cow/day)</td>
<td>41</td>
<td>46</td>
<td>51</td>
<td>56</td>
<td>61</td>
<td>66</td>
</tr>
<tr>
<td>P Excretion (g) per unit milk (kg)</td>
<td>2.7</td>
<td>1.8</td>
<td>1.5</td>
<td>1.2</td>
<td>1.1</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Shaver, Midwest Manure Summit, 2017
## Impact of Cow Weight on Manure Output and Feed Efficiency

<table>
<thead>
<tr>
<th></th>
<th>11,610</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk per Cow per Lactation (kg)</td>
<td>11,610</td>
<td></td>
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<tr>
<td>Milk (kg/cow/day)</td>
<td>36</td>
<td></td>
<td></td>
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<tr>
<td>Body Weight (kg)</td>
<td>635</td>
<td>680</td>
<td>726</td>
<td>771</td>
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<tr>
<td>DMI (kg/cow/day)</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>Feed Efficiency</td>
<td>1.57</td>
<td>1.51</td>
<td>1.46</td>
<td>1.41</td>
</tr>
<tr>
<td>Manure Output (kg/cow/day)</td>
<td>61</td>
<td>63</td>
<td>66</td>
<td>68</td>
</tr>
<tr>
<td>Manure (kg) per Unit Milk (kg)</td>
<td>1.69</td>
<td>1.75</td>
<td>1.83</td>
<td>1.89</td>
</tr>
</tbody>
</table>

Shaver, Midwest Manure Summit, 2017
Excess P in Diet

Satter et al, 2005
Nitrogen Management

(54 Wisconsin dairy farms)

Practice | No | Yes | Increase due to practice
---|---|---|---
Balance rations | |
Feed TMR | |
Use Posilac | |
Milk 3x/d | |

Milk N : Manure N Ratio

Milk 20-35%
Manure 65-80%

Powell, Midwest Manure Summit, 2015
Enteric Methane

5% CH₄ out

95% CH₄ out

feed in
Strategies to Reduce Methane Emissions

**Feed management and nutrition**
- Increase milk production (less methane per unit of milk)
  - Increase dry matter intake
  - Improve genetic selection
- Improve forage intake
  - Decrease forage to concentrate ratio
  - Decrease nature forages
- Improve feed supplementation
  - Increase lipids and fats
  - Include feed additives

**Genetics**
- Improve breeding (more productive cows)
- Improve cow’s health
- Genetic selection based on microorganism population in the rumen

**Management practices**
- Reduce number of unproductive animals in the heard
- Reduce cow disease
- Improve housing and feeding technologies
Maximum Potential Reduction of Enteric Methane

Potential reduction of methane emissions per kg milk (%)

- Rumen modifiers
- Feeding and nutrition
- Genetic selection
- Other management practices
- All approaches combined

Knapp et al. (2014)
Manure Processing

• Composting
• Anaerobic digestion
• Solids removal
  ▪ Mechanical solid/liquid separation
  ▪ Bedding recovery units
  ▪ Settling
• Sand removal
• Pelleting
• Drying
• Biochar
• Advanced treatment
Survey results: Manure management practices

Manure processing

- Only permitted facilities adopt most processing systems except composting
- AD is coupled with solid-liquid separation (mostly screw press) and/or sand separation
- Modified plug flow and plug flow are the most common AD systems
What is Anaerobic Digestion?

- Biological breakdown of organic materials (called feedstocks)
- Absence of oxygen (anaerobic conditions)
- Produced biogas - methane ($CH_4$) and carbon dioxide ($CO_2$)
Methane burning off a manure storage in central Pennsylvania
FIGURE 2.1: BIOMASS POWER GENERATION TECHNOLOGY MATURITY STATUS

SOURCE: EPRI, 2011
Agricultural Digesters in the U.S.

Click on a project to view details.

Dairy  Hog  Poultry  Beef  Mixed

USEPA AgSTAR, 2017
Agricultural Digesters

- 247 digesters in the U.S.
- 37 in Wisconsin
  - 35 different facilities
  - All dairy facilities
  - All liquid manure based systems
- ~300,000 metric tons CO$_2$ eq/year removal
  - Equal to:
    - 63,000 passenger cars, or
    - 322 million lbs of coal burned, or
    - 83 wind turbines
- 229 WI dairy CAFO (>1,000 Animal units) facilities
  - ~12% have digesters

<table>
<thead>
<tr>
<th>Animals (No. of head)</th>
<th>Operations</th>
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<tbody>
<tr>
<td>&lt; 1,000</td>
<td>9</td>
</tr>
<tr>
<td>1,000-2,000</td>
<td>9</td>
</tr>
<tr>
<td>&gt; 2,000</td>
<td>19</td>
</tr>
</tbody>
</table>
European Anaerobic Digestion Systems

- Over 13,000 digesters installed in European nations
- Nearly 10,000 in Germany alone
- Increased revenue for energy due to policy
- Many facilities have upgrading technology
Agricultural Digestion Systems

Diagram showing the process of manure digestion:
- Manure collected
- Manure进入 digesters
- Biogas produced
- H2S removal
- Biogas upgraded
- Compressed biogas for fuel
- Manure storage
- Land application
- Solid manure burned for heat
- Digester for solid-liquid separation
- Electricity from biogas
- Grid connection
- Natural gas pipeline for upgraded biogas
- Compressor for biogas upgrade
Anaerobic Digestion Feedstocks

- Cheese Whey
- Yard Clippings
- Cattle Manure
- Cucumber Waste
- Municipal Organics
- Dairy Manure
- Food Processing Waste
- Human Waste
- Grasses
- Swine Manure
- Vegetables
Biogas Yield

- Malze: 200 m³/t
- Grasses: 110 m³/t
- Mangel: 75 m³/t
- Used fats: 800 m³/t
- Fatty wastes: 400 m³/t
- Vegetable oil: 350 m³/t
- Sewage waste: 80 m³/t
- Distillery waste: 80 m³/t
- Dairy waste: 55 m³/t
- Fruit and vegetables: 35 m³/t
- Poultry manure: 35 m³/t
- Cattle manure: 30 m³/t
- Pig manure: 25 m³/t

Kestutis Navickas. 2007. Bioplin Tehnologija in Okolje,
Anaerobic Digestion
Dry Digestion

OshKosh Dry Digester, BIOFerm
Covered Lagoons
Community Digesters
Dane County Digester, 2011
Small Scale Digesters
Small Scale Digesters
Micro Scale Digestion - Bolivia
Biogas Use – Direct Burn
Biogas Use – Compressed Fuel (bioCNG)
Biogas Use – Absorption Chiller
Digestate

- Must be disposed
- Liquid and solid commonly used for fertilizer
- Solids potential for higher value products
- AD results in:
  - nutrient mineralization
  - odor reduction
  - pathogen reduction
  - antibiotic degradation
Benefits - Pathogen Reduction

Mean Pathogen Concentration (gc/gm)

Bovine Polyomavirus
Swine Manure
Hansen et al. 2006, Applied Engineering in Agriculture
• Slurry concentrations of malodorous VFA were reduced 79-97% from AD
• Odor concentration above undisturbed slurry store reduced (higher odors after mixing)
• Land application odor reductions:
  ▪ 17% anaerobic digestion
  ▪ 50% anaerobic digestion and solid liquid separation

Orzi et al., 2015, Science of the Total Environment
• Odors reduced 98%
• P2-P6 are pig slurries
• VFA destruction related to measured odor reductions
Benefits - Antibiotic Degradation

- Many antibiotics to be tested
- Not many studies to date
- May increase intermediates
- Beef manure studies by Arikan (2006, 2007, 2008) found some degradation in initial component, increases in some intermediaries

Alvarez et al., 2010, Bioresource Technology
- Fate of antibiotics in pig manure in AD
- oxytetracycline (OTC) and chlortetracycline (CTC)
- Reduction in antibiotics over time, as well as methane production
- Antibiotics adsorbed to solids increasing duration for destruction
Global Warming Potential

kg CO2-eq ton⁻¹ excreted manure

-60.00 -50.00 -40.00 -30.00 -20.00 -10.00 0.00 10.00

SLS  AD  AD+SLS

-60 -50 -40 -30 -20 -10 0

CO2(f)  CO2(b)  N2O(f)  N2O(b)  CH4(f)  CH4(b)  NET
Ammonia Emissions

NH\textsubscript{3} emissions (kg NH\textsubscript{3} per ton of excreted manure)

Base case (no digestion)

Anaerobic digestion
Application and Nitrogen Availability
• In the last 15 years there were 52 digesters that were shut down (8 of those were in Wisconsin)
• Many reasons for shutdowns from economic to explosions
• Of the 52 shutdown projects
  • 42 shutdown projects report dates of operation
  • 18 were closed within 3 years of start (or 43%)
  • 26 were closed within 5 years of start (or 62%)
Economics – Rosendale

Annual O&M: $1.2M USD

- Plant Maintenance: 20%
- Biogas Clean Up: 14%
- CHP Maintenance: 9%
- Utilities: 12%
- Leases: 8%
- Everything else (lab testing, permits, trucking, etc...): 10%
- Staffing: 27%

Source: Brian Langolf, UW-Oshkosh, Rosendale Digester. Presented at the 2017 Midwest Manure Summit
# Economics

<table>
<thead>
<tr>
<th>Income</th>
<th>Expenses</th>
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<tbody>
<tr>
<td>Electrical</td>
<td>Maintenance</td>
</tr>
<tr>
<td>$ 420,000</td>
<td>$250,000</td>
</tr>
<tr>
<td>Bedding</td>
<td>Manure Application</td>
</tr>
<tr>
<td>$ 275,000</td>
<td>$400,000</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Reduced Manure App. $(30,000)</td>
</tr>
<tr>
<td>$ 440,000</td>
<td></td>
</tr>
<tr>
<td>Heating</td>
<td>Depreciation</td>
</tr>
<tr>
<td>$ 30,000</td>
<td>$115,000</td>
</tr>
<tr>
<td>Carbon C</td>
<td>Carbon Credit fees</td>
</tr>
<tr>
<td>$ 125,000</td>
<td>$21,000</td>
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<tr>
<td>Tipping</td>
<td>Total</td>
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<tr>
<td>$ 75,000</td>
<td>$756,000</td>
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<td>Tax Credit</td>
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<tr>
<td>$ 40,000</td>
<td></td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>$1,384,000</td>
<td>$756,000</td>
</tr>
</tbody>
</table>

Does not include expenses incurred during cleanout process.

Return on Investment: $628,000/$2,200,000 = 28.5 %

Bob Nagel, 2013 Midwest Manure Summit
Compost Process

\[ \text{Air} + \text{Microbes} = \text{CO}_2 + \text{H}_2\text{O} \text{ Heat Humus} \]
Composting Benefits

- Stabilized Product
- Reduced odor
- Reduction in volume and moisture
- Consistent product
- Potential for additional revenue stream
- Reduction in pathogens
- Weed seed deactivation
## Compost Conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>Reasonable range</th>
<th>Preferred range</th>
</tr>
</thead>
<tbody>
<tr>
<td>C:N</td>
<td>20:1 – 40:1</td>
<td>25:1 - 30:1</td>
</tr>
<tr>
<td>Moisture (%)</td>
<td>40 – 65</td>
<td>50 - 60</td>
</tr>
<tr>
<td>O₂ (%)</td>
<td>&gt; 5</td>
<td>&gt; 5</td>
</tr>
<tr>
<td>Particle size (d, in)</td>
<td>1/8 – 1/2</td>
<td>Varies *</td>
</tr>
<tr>
<td>pH</td>
<td>5.5 - 9.0</td>
<td>6.5 - 8.0</td>
</tr>
<tr>
<td>Temperature (F)</td>
<td>110 - 150</td>
<td>130 - 140</td>
</tr>
</tbody>
</table>

* Depends on materials

Adapted from NRAES-54
Temperature

Figure 2. Temperature Ranges of Mesophilic and Thermophilic Bacteria (Adapted from McNelly, 1989)
Time and Temperature

Compost temperature vs. Days

- **Curing stage**
- **Compost turned**
Figure 10-31  Static pile composting schematic

- Screening compost
- Compost
- Water trap for condensate
- Perforated pipe
- Fan or blower
- Filter pile for absorbing odor
Windrow Method

Figure 10–30  Windrow schematic

- Concave to collect moisture (if needed)
- Normal curvature

Adjust for size
Windrow
In-Vessel Method

Air plenum or gravel base with aeration pipe underneath

Raw materials loaded

Blowers (one for each aeration zone in every bed)

Turning machine (moves towards raw materials loading end)

Carriage to transport the turning machine to the next bed

Compost discharged
In-Vessel
In-Vessel
Nutrient Densification

• Separate streams to produce multiple products of various strengths of phosphorus
• Must examine entire manure handling system to see benefits
• Numerous technologies
  ▪ Screw press
  ▪ Centrifuge
  ▪ Settling basins
• Varying cost and complexity
Manure Separation Systems

Mechanical or Gravitational Separator

Filtrate (liquid)

Fiber (solid)
Mechanical Separation Systems
Screw Press Separator
## Screens

<table>
<thead>
<tr>
<th>Screen size [b] (mm)</th>
<th>TSS</th>
<th>VSS</th>
<th>TKN</th>
<th>TP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount retained (g/L)</td>
<td>Fraction of TSS (%)</td>
<td>Amount retained (g/L)</td>
<td>Fraction of VSS (%)</td>
</tr>
<tr>
<td>3.360</td>
<td>0.74</td>
<td>6.4</td>
<td>0.38</td>
<td>6.7</td>
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<tr>
<td>2.000</td>
<td>2.76</td>
<td>23.9</td>
<td>0.94</td>
<td>16.6</td>
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<tr>
<td>1.588</td>
<td>3.24</td>
<td>28.1</td>
<td>1.78</td>
<td>31.4</td>
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<td>1.000</td>
<td>3.78</td>
<td>32.8</td>
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<tr>
<td>0.794</td>
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<td>27.6</td>
<td>2.18</td>
<td>38.5</td>
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<td>0.590</td>
<td>3.98</td>
<td>34.5</td>
<td>2.48</td>
<td>43.8</td>
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<tr>
<td>0.500</td>
<td>3.92</td>
<td>34.0</td>
<td>1.54</td>
<td>27.2</td>
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<tr>
<td>0.297</td>
<td>4.22</td>
<td>36.6</td>
<td>1.90</td>
<td>33.6</td>
</tr>
<tr>
<td>0.250</td>
<td>4.82</td>
<td>41.8</td>
<td>2.14</td>
<td>37.8</td>
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</tbody>
</table>
## Screens with polymers

<table>
<thead>
<tr>
<th>Polymer rate (mg/L)</th>
<th>TSS</th>
<th>VSS</th>
<th>TKN</th>
<th>TP</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>PAM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>64.9</td>
<td>64.3</td>
<td>18.9</td>
<td>19.6</td>
</tr>
<tr>
<td>60</td>
<td>71.6</td>
<td>73.8</td>
<td>37.1</td>
<td>34.4</td>
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<tr>
<td>120</td>
<td>75.9</td>
<td>74.2</td>
<td>35.8</td>
<td>33.8</td>
</tr>
<tr>
<td>180</td>
<td>82.8</td>
<td>79.8</td>
<td>48.1</td>
<td>44.4</td>
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<tr>
<td>240</td>
<td>86.8</td>
<td>83.5</td>
<td>55.9</td>
<td>52.0</td>
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<tr>
<td>300</td>
<td>90.0</td>
<td>87.6</td>
<td>63.9</td>
<td>58.9</td>
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<tr>
<td>360</td>
<td>92.7</td>
<td>92.4</td>
<td>65.0</td>
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<tr>
<td>420</td>
<td>94.9</td>
<td>92.9</td>
<td>74.0</td>
<td>66.4</td>
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<tr>
<td>480</td>
<td>95.0</td>
<td>93.0</td>
<td>73.1</td>
<td>64.9</td>
</tr>
</tbody>
</table>

Note: [a] (\%)
Chemical & polymer P separation

- Significant additions of chemical and polymer
- 80-90% TP removal
- Dairy manure at 0.87% & 1.5% TS
- Chemical additions alone cost $0.01
Centrifuge
Bedding Recovery Unit
Inclined Screen
Settling Basin

Removal of approximately 28% TP in settling basins with no addition (initial TS of ~4%)
## Mass Separator Efficiency

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass separation efficiency (%)&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids</td>
<td>45</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>18</td>
</tr>
<tr>
<td>Organic nitrogen</td>
<td>20</td>
</tr>
<tr>
<td>Inorganic nitrogen</td>
<td>15</td>
</tr>
<tr>
<td>Total phosphorous</td>
<td>21</td>
</tr>
</tbody>
</table>

<sup>1</sup>From Chastain (2013) based on (Gooch, Inglis, and Czymmek 2005; Chastain, Vanotti, and Wingfield 2001)
Moisture of Solids by Separator Type

![Bar chart showing moisture levels for different separator types: Screw Press, Blower, Centrifuge, BRU, Dryer. The Centrifuge has the highest moisture level, followed by Screw Press, Blower, BRU, and Dryer with the lowest.](chart.png)
### N-P-K

<table>
<thead>
<tr>
<th>Concentration</th>
<th>N (g/kg)</th>
<th>P$_2$O$_5$ (g/kg)</th>
<th>K$_2$O (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td>50</td>
<td>18</td>
<td>41</td>
</tr>
<tr>
<td>Liquid</td>
<td>101</td>
<td>27</td>
<td>75</td>
</tr>
<tr>
<td>Solid</td>
<td>15</td>
<td>14</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratio</th>
<th>N</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Liquid</td>
<td>4</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Solid</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>
Separation and Emissions Reductions

Fig. 4. Density curves for dry matter (DM) removal efficiency (RE) and separation index (SI).

Low vs High Efficiency

![Bar chart showing mass distribution profiles of digestate mechanical separation according to low (a) and high (b) efficiency categories.](image)

**Fig. 5.** Mass distribution profiles of digestate mechanical separation according to low (a) and high (b) efficiency categories. The solid fraction distribution correspond to the separation index. The numbers in the right indicate the number of observations. FM: fresh matter. DM: dry matter. VS: volatile solids. TN: total nitrogen. Norg: organic nitrogen. TAN: total ammoniacal nitrogen. P: total phosphorus. K: total potassium. S: total sulfur. Ca: total calcium. Mg: total magnesium.

# WI Separation Efficiencies

<table>
<thead>
<tr>
<th>Separator</th>
<th>$RE_{DM}$</th>
<th>In DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>0.41</td>
<td>7.9</td>
</tr>
<tr>
<td>SP</td>
<td>0.30</td>
<td>5.3</td>
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<td>0.52</td>
<td>8.1</td>
</tr>
<tr>
<td>SP</td>
<td>0.36</td>
<td>5.0</td>
</tr>
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<td>SP</td>
<td>0.32</td>
<td>4.9</td>
</tr>
<tr>
<td>SP</td>
<td>0.33</td>
<td>4.9</td>
</tr>
<tr>
<td>SP</td>
<td>0.33</td>
<td>5.9</td>
</tr>
<tr>
<td>C</td>
<td>0.39</td>
<td>4.6</td>
</tr>
<tr>
<td>SP</td>
<td>0.41</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td>Slurry</td>
<td>Liquid</td>
</tr>
<tr>
<td>-----</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>SP</td>
<td>10.1</td>
<td>11.5</td>
</tr>
<tr>
<td>SP</td>
<td>6.6</td>
<td>5.8</td>
</tr>
<tr>
<td>SP</td>
<td>8.9</td>
<td>11.6</td>
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<td>6.7</td>
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<td>SP</td>
<td>6.9</td>
<td>6.4</td>
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<tr>
<td>SP</td>
<td>6.3</td>
<td>6.5</td>
</tr>
<tr>
<td>SP</td>
<td>6.5</td>
<td>7.6</td>
</tr>
<tr>
<td>SP</td>
<td>6.5</td>
<td>8.1</td>
</tr>
<tr>
<td>C</td>
<td>7.8</td>
<td>17.3</td>
</tr>
</tbody>
</table>

WI Slurry TN:TP Average 6.5 for TS<11%
Dissolved air flotation

- Air is dissolved in the waste water stream and injected at bottom of unit
- Fine solids are carried or “floated” to surface
- Chemical addition of polymers and flocculent is needed for optimum efficiency

R. Sheffield
## Efficiency comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Initial TS (%)</th>
<th>TP Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Settling Basin</td>
<td>~4</td>
<td>28</td>
</tr>
<tr>
<td>Screw Press</td>
<td>variable</td>
<td>15-24</td>
</tr>
<tr>
<td>Centrifuge</td>
<td>variable</td>
<td>40-60</td>
</tr>
<tr>
<td>Dewatering using Geotextiles</td>
<td>0.71</td>
<td>46</td>
</tr>
<tr>
<td>Inclined Plane</td>
<td></td>
<td>53</td>
</tr>
<tr>
<td>Screens</td>
<td>0.4-3.2</td>
<td>&lt;17</td>
</tr>
<tr>
<td>Screens with Polymers</td>
<td>0.4-3.2</td>
<td>34-65</td>
</tr>
<tr>
<td>Chemical Precipitation</td>
<td>0.87-1.5</td>
<td>80-90</td>
</tr>
</tbody>
</table>
Advanced Treatment
Figure 3. Modeled ammonia losses from manure management in a dairy system with no manure processing (base case), a system with solid-liquid separation (SLS), a system with anaerobic digestion (AD), and a system combining solid-liquid separation and anaerobic digestion (AD+SLS) (Aguirre-Villegas et al. 2014).

## Percent of TN that is NH4+NH3

<table>
<thead>
<tr>
<th></th>
<th>Slurry</th>
<th>Liquid</th>
<th>Solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP</td>
<td>48%</td>
<td>56%</td>
<td>4%</td>
</tr>
<tr>
<td>SP</td>
<td>37%</td>
<td>37%</td>
<td>1%</td>
</tr>
<tr>
<td>SP</td>
<td>61%</td>
<td>63%</td>
<td>2%</td>
</tr>
<tr>
<td>SP</td>
<td>58%</td>
<td>56%</td>
<td>1%</td>
</tr>
<tr>
<td>SP</td>
<td>58%</td>
<td>82%</td>
<td>1%</td>
</tr>
<tr>
<td>SP</td>
<td>40%</td>
<td>42%</td>
<td>0%</td>
</tr>
<tr>
<td>SP</td>
<td>55%</td>
<td>60%</td>
<td>2%</td>
</tr>
<tr>
<td>SP</td>
<td>50%</td>
<td>64%</td>
<td>3%</td>
</tr>
<tr>
<td>C</td>
<td>60%</td>
<td>67%</td>
<td>4%</td>
</tr>
</tbody>
</table>
Nitrogen Mineralization of Solid Fraction

- DEC – centrifuges
- KEM – polymer or other chemical pretreatment for flocculation and separation
- MEC - mechanical separation (vibrating screens, screw presses, etc.)

Conclusions

• Separation systems are highly variable
• Investigating improved performance may have significant advantages in terms of nutrient separation
• Most separators currently installed are low efficiency
• Higher removal efficiency for phosphorus than nitrogen
• Solids fraction generally have low available nitrogen
Manure Storage
Manure Storage & Timing

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

- Ground thaws
- Planting
- Harvest
- Ground freezes

Legend:
- Black: Frozen soils
- Grey: Growing season
- Manure application allowable
- Blue: Precipitation
- Green: Growing season
Survey results: Manure management practices

Storage

• Below ground concrete and clay lined earthen basins
• Permitted facilities have multiple and a wider variety of systems

Methane Emissions

## Nitrogen Retention in Different Manure-Handling Systems

<table>
<thead>
<tr>
<th>System</th>
<th>Nitrogen Lost, %</th>
<th>Nitrogen Retained, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily scrape and haul</td>
<td>20-35</td>
<td>65-80</td>
</tr>
<tr>
<td>Manure pack</td>
<td>20-40</td>
<td>60-80</td>
</tr>
<tr>
<td>Open lot</td>
<td>40-55</td>
<td>45-60</td>
</tr>
<tr>
<td>Deep pit (poultry)</td>
<td>25-50</td>
<td>50-75</td>
</tr>
<tr>
<td>Litter</td>
<td>25-50</td>
<td>50-75</td>
</tr>
<tr>
<td>Under floor pit</td>
<td>15-30</td>
<td>70-85</td>
</tr>
<tr>
<td>Aboveground tank</td>
<td>10-30</td>
<td>70-90</td>
</tr>
<tr>
<td>Holding pond</td>
<td>20-40</td>
<td>60-80</td>
</tr>
<tr>
<td>Anaerobic lagoon</td>
<td>70-85</td>
<td>15-30</td>
</tr>
</tbody>
</table>

Adapted from: Livestock Waste Facilities Handbook, MWPS
<table>
<thead>
<tr>
<th>Description</th>
<th>Volume (cu ft/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>1,676,000</td>
</tr>
<tr>
<td>Delete Barnyard &amp; Reduce Feed Stor. Runoff</td>
<td>1,483,000</td>
</tr>
<tr>
<td>Remove Plate Cooler</td>
<td>1,067,000</td>
</tr>
<tr>
<td>Valved Sprinklers</td>
<td>1,002,000</td>
</tr>
<tr>
<td>Feed Storage Runoff</td>
<td></td>
</tr>
<tr>
<td>Sprinkling</td>
<td></td>
</tr>
<tr>
<td>Waterers</td>
<td></td>
</tr>
<tr>
<td>Plate Cooler</td>
<td></td>
</tr>
<tr>
<td>Manure</td>
<td></td>
</tr>
<tr>
<td>Udder Wash</td>
<td></td>
</tr>
<tr>
<td>Waste Milk</td>
<td></td>
</tr>
<tr>
<td>Feed Stor. Runoff</td>
<td></td>
</tr>
<tr>
<td>Barn Yard Runoff</td>
<td></td>
</tr>
<tr>
<td>Barn Yard Runoff</td>
<td></td>
</tr>
<tr>
<td>Pail Wash</td>
<td></td>
</tr>
<tr>
<td>Water Softener</td>
<td></td>
</tr>
<tr>
<td>Bulk Tank</td>
<td></td>
</tr>
<tr>
<td>Milk Sys Wash</td>
<td></td>
</tr>
<tr>
<td>Milk Sys Wash</td>
<td></td>
</tr>
<tr>
<td>Waterers</td>
<td></td>
</tr>
<tr>
<td>Leaks</td>
<td></td>
</tr>
<tr>
<td>Parlor Wash</td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
</tr>
<tr>
<td>Bedding</td>
<td></td>
</tr>
<tr>
<td>Sprinkling</td>
<td></td>
</tr>
<tr>
<td>Sprinkling</td>
<td></td>
</tr>
<tr>
<td>Plate Cooler</td>
<td></td>
</tr>
<tr>
<td>Plate Cooler</td>
<td></td>
</tr>
</tbody>
</table>
Manure Storage Covers

• Impermeable covers
  ▪ reduce all forms of emissions and odors
  ▪ Can be expensive and difficult to manage

• Permeable covers (natural crust, biomass covers)
  ▪ Straw covers 15 cm and 30 cm straw covers reduce NH\textsubscript{3} emissions by 28% and 90% (VanderZaag et al. 2009)
  ▪ Chopped straw increases emissions of CH\textsubscript{4} (Berg et al., 2006; Guarino et al., 2006)
  ▪ Straw covers increase emissions of carbon dioxide (CO\textsubscript{2}) and nitrous oxide (N\textsubscript{2}O) due to aerobic conditions at the surface and the increased organic material (VanderZaag et al., 2009)
  ▪ Limited life span (straw 3 months – Guarino et al. 2006)
  ▪ Other natural permeable covers: chopped corn stalks, saw dust, rice hulls, ground corn cobs, and grass clippings also reduce NH\textsubscript{3} emissions (Vanderzaag et al., 2008) similar issues to straw
Manure variation

Caused by:
- Animal type
- Diet
- Bedding material
- Additional by-products
- Storage
- Processing

Impacts:
- Stratification
- Settling of solids and nutrients
- Increased solids and phosphorus in settled material
- Nitrogen losses
Manure Agitation
Manure Agitation
## Hydrogen Sulfide (ATSDR 2006)

<table>
<thead>
<tr>
<th>Property</th>
<th>Concentration in air (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical background level</td>
<td>0.0002</td>
</tr>
<tr>
<td>Odor threshold (AIHA 1989)</td>
<td>0.001-0.008</td>
</tr>
<tr>
<td>Offensive odor, headache</td>
<td>0.3</td>
</tr>
<tr>
<td>Very offensive odor</td>
<td>3-5</td>
</tr>
<tr>
<td>Asthmatics affected</td>
<td>2</td>
</tr>
<tr>
<td>Human flatus</td>
<td>3-18</td>
</tr>
<tr>
<td>Olfactory paralysis</td>
<td>150</td>
</tr>
<tr>
<td>Central nervous system depression, loss of consciousness, neurological problems may persist</td>
<td>&gt;500</td>
</tr>
<tr>
<td>Lung paralysis, collapse, death</td>
<td>&gt;600-1,000 (concentrations in actual events are uncertain)</td>
</tr>
</tbody>
</table>
Gas Dispersion

- Open and free to disperse
- Decrease gas concentration
- Lower Concentration
- Highest Concentration
- Wind
Conditions which Increase Gas Production and/or Risk

- Increased gas production
  - Increased temps increase microbial activity
- Decrease in dispersion (vertical or horizontal)
  - Still conditions & inversions
  - Covers (natural crust, permeable, and impermeable covers)
  - Structures
- Distance from source (closer increases risk)
- Increased $\text{H}_2\text{S}$ levels
  - Excess sulfur
Limited Gas Dispersion

Barn

- Highest Concentration
- Lower Concentration
- Decrease gas concentration

Limited dispersion due to structure

All can still be toxic

Manure

Under barn manure storage
Sulfur Content of Manure

- Excess sulfur in animal diets exits animal in manure
- Increased manure sulfur content = increased H$_2$S production
- Liquid and slurry cattle manure
  - over 22,000 samples of livestock and poultry
  - median total sulfur per thousand gallons was 0.6 to 3.2 pounds (0.3 to 1.5 kg) (Laboski and Peters 2012)
  - maximum measured values were upward of 450 pounds (204 kg) per thousand gallons
- Additional sulfur in manure storage from byproducts (e.g. silage runoff, spoiled feed, feed additives – distillers grains, and bedding additives – gypsum)
Manure Land Application
Manure Application Techniques
Manure Application Techniques
Example: Irrigation

Center Pivot
Traveling Gun
**Land application**

- Surface application is common in small farms and injection and surface application are used in larger farms.

- Frequency of application decreases with farm size.

Survey results: Manure management practices

- Hauling distance increases with farm size until a point in the permitted facility group where it decreases
  - Larger farms have less land per AU than smaller farms

\[ y = -5 \times 10^{-7}x^2 + 0.0033x + 1.2478 \]

\[ R^2 = 0.434 \]
Wisconsin Manure Advisory System

How To Use The Map Downloader

1. Click on the map. The map will open in a new window.
2. Click on the map again to download the map.
3. The map will be downloaded to your computer.

Fall N Restrictions

No Winter Application (slope > 12%)

Winter Restrictions (if slope > 9%)

Perennial Streams

Intermittent Streams

Source: USDA- NRCS SSSRGO 2006 MAP Analyst

http://www.manureadvisorysystem.wi.gov/
SNAP-Plus is a Microsoft Windows® based Nutrient Management Planning software program designed for the preparation of nutrient management plans in accordance with Wisconsin's Nutrient Management Standard Code 596. The program is available for download from the “Current Version” link. Updates are released periodically to add new features and bug fixes.

SNAP-Plus will calculate:

- Crop nutrient (N, P₂O₅, K₂O) recommendations for all fields on a farm taking into account legume N and manure nutrient credits consistent with University of Wisconsin recommendations.
- A RUSLE2-based soil loss assessment that will allow producers to determine whether fields that receive fertilizer or manure applications meet tolerable soil loss (T) requirements.
- A rotational Phosphorus Index value for all fields as required for using the P Index for phosphorus management.
- A rotational P balance for using soil test P as the criteria for phosphorus management.

SNAP-Plus is produced by the

Department of
Soil Science
University of Wisconsin-Madison

SNAP-Plus is supported by:

DATCP
NRCS
Natural Resources Conservation Service
UW Extension
Achieving a Nutrient Balance

• **Causes of Imbalance**
  - Feed Imported to the Farm from a Distance
  - Applying Excess Manure Close to Farmstead
  - Excessive Nutrient Feeding
  - Not Using a Nutrient Management Plan

• **Achieving a Balance**
  - Understand all nutrients sources and fates
  - Balance nutrients on the farmstead (this goes beyond just the field level)
  - Use nutrient managements plans
  - Improve efficiencies
Remember First – Nutrient Balance
Example: Phosphorus Relationships
Example: Phosphorus Relationships

Flow diagram illustrating the cycle of phosphorus in agricultural land:
- **Land application**: Application of phosphorus to the soil.
- **Soil build-up**: Phosphorus accumulates in the soil.
- **Crops**: Phosphorus is taken up by crops.
- **Harvest**: Phosphorus is removed from the soil during harvest.
- **Runoff containing phosphorus**: Phosphorus is washed away in runoff.

The diagram uses symbols to represent phosphorus (P) in different stages of the cycle.
536 square miles (1,345 km²)
Spans three counties
87% of area in Dane County
Crop production is 47% of the watershed area
Livestock production is one of the key economic activities

Example: Yahara Watershed

Watershed Nutrient Balance
Distribution of Yahara Watershed Livestock Farms

Livestock production farms by type
- Dairy
- Beef
- Hogs; Horses; Sheep

Scale: 0 - 20 Miles
Manure Phosphorus Production In The Upper Yahara Sub-Watershed Study Area

Annual manure P production by farm (ton P/year)

- < 1
- 1 - 5
- 5 - 10
- 10 - 20
- 20 - 50
Phosphorus Uptake by Field Based on Crop Rotations in the Upper Yahara Sub-Watershed Study Area
Manure Movement - $0/pound P
Manure movement - $30/pound P
P Imbalance - $0/pound P
P Imbalance - $15/pound P
Model results: GHG emissions

- As farm size increases manure type transitions to more liquid, requiring long term storage which is the main driver for emissions.
- Economies of scale justify manure processing, that can reduce GHG emissions significantly.

Grazing scenarios emit less GHGs than confined scenario, but AD is effective in significantly reducing GHGs.

Welcome to our Virtual Dairy Farm

Here you can explore the systems that make up modern dairy farms in the United States. If you wish, you can go deep into the science that makes modern dairy farming efficient, humane, environmentally conscious, and economically sustainable.

1500 Cow Farm

Explore the ways large farm operators handle their herds by clicking on the numbered objects. There are many similarities between a 1,500 and 150 cow dairy farm, but farm systems change as scale grows to allow for increased efficiency and output. Flip back and forth between our 1500- and 150-cow farms to see how the layout changes.
Thank You!

rebecca.larson@wisc.edu
Silage Storage
Loading and Compaction
Dry Weather Leachate
Dry Weather Silage Leachate
Impacts of Silage Runoff
## Annual Nutrient Loading

<table>
<thead>
<tr>
<th>Site</th>
<th>TP Year 1</th>
<th>TP Year 2</th>
<th>TKN Year 1</th>
<th>TKN Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>762</td>
<td>1,422</td>
<td>3,259</td>
<td>4,973</td>
</tr>
<tr>
<td>E</td>
<td>689</td>
<td>1,165</td>
<td>2,944</td>
<td>4,320</td>
</tr>
<tr>
<td>F</td>
<td>390</td>
<td></td>
<td>2,184</td>
<td></td>
</tr>
</tbody>
</table>
Phosphorus Losses from Cropland

Map 28  Estimated average annual per-acre phosphorus loss summed over all loss pathways (elemental P)

Note: Values were derived using the EPIC model for 1997 NRI cropland sample points. Results for some sample points are not shown. The mapping technique is designed to highlight spatial trends; localized interpretations may be misleading. See text for explanation of how the map and the estimates were made.

NRCS, 2006
Equivalent Crop Acres

- Nutrient losses from crop fields range are reported from 2.2 to 10.1 kg of phosphorus per hectare per year (NRCS, 2006)
- At 2.2 kg P/ha/yr, silage storage systems represent anywhere from 177 to 636 times the area
- A 0.5-hectare total feed storage pad area it would have the equivalent runoff loading of 88 to 323 hectares of crop fields