Management of Farmstead Area Runoff: Potential of Agricultural Filter Strips

Becky Larson
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Department of Biological Systems Engineering
University of Wisconsin-Madison
Outline

- Background
- Source Characterization
- Field Study
- Laboratory Study
- Laboratory to Field Scale Comparison
- Conclusions
Farmstead Runoff

- Potential diffuse pollution source
- Environmental concerns, potential for ground and surface water contamination
- Cost
- Need for assessment of current practices
- Lack of viable data for reliable performance evaluation
  - Research examined feedlot runoff as a whole, no source investigation
  - Lack of data for infiltration
- Implications for regulations and current applications
Research

1. Source Characterization

2. Field Scale Agricultural Filter Strips

3. Soil Column Laboratory Investigation
Effective treatment is dependent upon effective management practices.

Management can effectively reduce contaminants in runoff and the loading to treatment systems through:

- source reduction
- reduction in transport mechanisms
- removal/degradation prior to reaching waterways

Practices include, but are not limited to:

- covering pollutant sources prior to precipitation
- sweeping impervious surfaces
- maintaining faces on feed bunkers

Management is time consuming.
Runoff Characterization Objectives

- Determine dairy feedlot water quality characteristics.
- Analyze individual source water quantity and quality impacts.
- Outline on-farm management practices to reduce the pollutant quantity and increase water quality.
Four additional areas were selected for sampling:

- Heat check lot
- Upright silos
- Bunker silos
- Main roadway

Michigan State University (MSU) Dairy Teaching and Research Farm

160 head dairy facility

In 2008, the existing system was modified to collect and divert water to two treatment system storage basins.

Comprehensive management plan

Grab samples will be collected during precipitation events

Laboratory analysis
Runoff Characterization – Laboratory and Data Analysis

- 9 storm events from July 2008 to June 2009
- Water quality analysis
  - 19 parameters
  - Includes nutrients, metals, oxygen demand, etc.
- Determine if there is a statistically significant difference in source water quality (SAS 2008)
  - ANCOVA – Rainfall, Season
  - Difference of least squares means
- Make farm recommendations
<table>
<thead>
<tr>
<th>Location</th>
<th>pH</th>
<th>Alkalinity (mg/L)</th>
<th>$\text{PO}_4^-$ (mg/L)</th>
<th>COD (mg/L)</th>
<th>$\text{BOD}_5$ (mg/L)</th>
<th>Ammonia (mg/L)</th>
<th>$\text{NO}_2^-$ (mg/L)</th>
<th>$\text{NO}_3^-$ (mg/L)</th>
<th>TKN (mg N/L)</th>
<th>$\text{SO}_4^-$ (mg/L)</th>
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<td>Bunker Silo</td>
<td>5.87</td>
<td>277</td>
<td>17</td>
<td>2320</td>
<td>900</td>
<td>18</td>
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<td>3180</td>
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<td>58</td>
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<td>168</td>
<td>11</td>
<td>1380</td>
<td>410</td>
<td>10</td>
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<td>54</td>
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<td>193</td>
<td>16</td>
<td>1910</td>
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<td>28</td>
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<td>445</td>
<td>8</td>
<td>790</td>
<td>240</td>
<td>23</td>
<td>0.08</td>
<td>8</td>
<td>54</td>
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<tr>
<td>Storage Basin 2</td>
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<td>36</td>
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## Average Source Concentrations

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<tr>
<th>Location</th>
<th>TS (mg/L)</th>
<th>VS (mg/L)</th>
<th>TSS (mg/L)</th>
<th>VSS (mg/L)</th>
<th>Mn (μg/L)</th>
<th>Fe (μg/L)</th>
<th>TOC (mg/L)</th>
<th>Conductance (μmhos/cm)</th>
<th>Cl (mg/L)</th>
<th>As (μg/L)</th>
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<tr>
<td>Bunker Silo</td>
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<td>1310</td>
<td>410</td>
<td>190</td>
<td>418</td>
<td>3950</td>
<td>990</td>
<td>1342</td>
<td>39</td>
<td>4.9</td>
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<tr>
<td>Heat Check Lot</td>
<td>4910</td>
<td>2060</td>
<td>1030</td>
<td>800</td>
<td>491</td>
<td>2530</td>
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<td>6730</td>
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<td>1880</td>
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<td>216</td>
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<td>440</td>
<td>836</td>
<td>39</td>
<td>1.7</td>
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<tr>
<td>Upright Silo</td>
<td>1540</td>
<td>1210</td>
<td>780</td>
<td>540</td>
<td>221</td>
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<td>450</td>
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<td>3200</td>
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<td>310</td>
<td>250</td>
<td>411</td>
<td>5560</td>
<td>790</td>
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<td>26</td>
<td>3.0</td>
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COD (Location Season)

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>COD (mg/L)</th>
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<tr>
<td>Heat Check Lot</td>
<td>A</td>
</tr>
<tr>
<td>Roadway</td>
<td>B</td>
</tr>
<tr>
<td>Storage Basin 1</td>
<td>B</td>
</tr>
<tr>
<td>Upright Silo</td>
<td>A</td>
</tr>
<tr>
<td>Bunker Silo</td>
<td>A</td>
</tr>
<tr>
<td>Storage Basin 2</td>
<td>A</td>
</tr>
</tbody>
</table>
Phosphorus (Location Season)

```
Sampling Location                  Total Phosphorus (mg PO₄/L)
---------------------------------      ----------------------
Heat Check Lot                    AB
Roadway                           BC
Storage Basin 1                   C
Upright Silo                      AB
Bunker Silo                       AB
Storage Basin 2                   A
```
Total Solids (Location Rainfall Season)

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>Total Solids (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Check Lot</td>
<td>A</td>
</tr>
<tr>
<td>Roadway</td>
<td>B</td>
</tr>
<tr>
<td>Storage Basin 1</td>
<td>B</td>
</tr>
<tr>
<td>Upright Silo</td>
<td>B</td>
</tr>
<tr>
<td>Bunker Silo</td>
<td>B</td>
</tr>
<tr>
<td>Storage Basin 2</td>
<td>B</td>
</tr>
</tbody>
</table>
TKN (Location Season)

Sampling Location

Heat Check Lot
Roadway
Storage Basin 1
Upright Silo
Bunker Silo
Storage Basin 2

TKN (mg/L)

0 20 40 60 80 100 120 140 160 180 200

A
B
B
A
B
B
Source Characterization Conclusions

- Determine dairy feedlot water quality characteristics.
- Analyze individual source water quantity and quality impacts.
- Outline on-farm management practices to reduce the pollutant quantity and increase water quality.
Source Characterization Conclusions

- Published data on feedlot water quality characteristics
- Analysis of statistically significant difference in source water quality, composite vs. source for water quantity
  - Manure and feed produce high runoff pollutant concentrations
  - Footprint of feedlot area, feed sources area greater concern
- Farm management practices:
  - Upright silo harvesting/loading critical
  - Open bunker feed large source problem, quantity and quality
  - Maintain feed faces, sweep, and cover feed
  - Exposed wastes pose a greater potential for contamination
  - Quantity generally larger concern than quality
    - Examine foot print and dilution
Mechanisms for pollutant removal

- Sediment trapping
- Plant uptake
- Infiltration treatment processes
  - Biological activity
  - Adsorption
  - Filtration
  - Oxidation

Microbial degradation rates dependent upon environmental conditions

Filter strip design: soil, slope, width, length, vegetation
Filter Strip Removal Mechanisms

Increased infiltration due to sheet flow

- Soil filtration and sequestration
- Sedimentation
- Microbial degradation
- Plant uptake
Field Scale Objectives

- Assess the surface and subsurface water quality at two field sites.

- Assess current practice standards in regards to operation and maintenance procedures.

- Determine if agricultural filter strips are an effective agricultural treatment/management option as designed, with a particular emphasis on metal leaching into groundwater.

- Determine treatment consistency throughout season and rainfall events.
Sampling

- Sampling Sept 2009 to June 2010
- 2 farmstead sites
  - MSU Dairy
    - 160 head
    - 10 sampling events
    - 2 filter strips, 1.14 acre and 1.28 acre drainage area
  - Small MI dairy
    - 40 head
    - 6 sampling events
    - 1 filter strip, 0.5 acre drainage area
- 17 water quality parameters analyzed
- Influent, surface and subsurface sampling
Filter Strip Design

- **NRCS Standard**
  - **Vegetation**
    - 37% Tuscany II Tall Fescue, 28% Smooth Bromegrass, 20% Graze N Gro Annual Ryegrass, and 12% Chiefton Reed Canarygrass

- **MSU Dairy**
  - 1.14 and 1.28 acre drainage areas
  - Settling (~90,000 gal) and distribution basins (~5,000 gal)
  - 400 ft long, 40 ft wide, 4% slope
  - Sandy loam soils
  - Pump system
  - Rock check at top and every 100 ft down slope

- **Small MI Dairy**
  - 0.5 acre drainage area
  - Settling basin
  - Bioretention basin
  - Gravity driven system
  - 110 ft long, 40 ft wide, 0.5% slope
  - Sandy soils
  - Gravity driven system
  - Rock check at top and 50 ft down slope
Filter Strip Field Treatment

HEAT CHECK FILTER STRIP
MIN. 9-INCHES TOPSOIL
DO NOT COMPACT

SILAGE AREA FILTER STRIP
MIN. 9-INCHES TOPSOIL
DO NOT COMPACT

9”–15”
COD MSU Dairy Influent vs. Effluent

![Graph showing COD MSU Dairy Influent vs. Effluent]

- **X-axis**: Influent COD (mg/L)
- **Y-axis**: Effluent COD (mg/L)

Data points for:
- FS1
- FS2
COD Influent vs. Effluent

![Graph showing COD Influent vs. Effluent](image-url)

- **MSU Dairy FS1**
- **MSU Dairy FS2**
- **Small MI Dairy 1.5 ft**
- **Small MI Dairy 2.5 ft**
Nitrogen

The graph shows the nitrogen concentration (mg N/L) in various locations, including MSU Dairy and Small MI Dairy. The locations include Influent FS1, Surface FS1, Subsurface FS1, Influent FS2, Surface FS 2, Subsurface FS2, Influent, Bioretention, Surface, Subsurface 1.5 ft, and Subsurface 2.5 ft. The concentrations are indicated by TKN (Total Kjeldahl Nitrogen) and Ammonia levels.
TKN MSU Dairy Influent vs. Effluent

![Graph showing comparison of Influent TKN vs. Effluent TKN for FS1 and FS2.]
Nitrate

Influent FS1
Surface FS1
Subsurface FS1
Influent FS2
Surface FS2
Subsurface FS2
Influent
Bioretention
Surface
Subsurface 1.5 ft
Subsurface 2.5 ft

NO3 (mg/L)

Location

MSU Dairy
Small MI Dairy
Field Treatment System

- Assess the surface and subsurface water quality at two field sites.

- Assess current practice standards in regards to operation and maintenance procedures.

- Determine if agricultural filter strips are an effective agricultural treatment/management option as designed, with a particular emphasis on metal leaching into groundwater.

- Determine treatment consistency throughout season and rainfall events.
Field Treatment System

- Examined data for two field sites at various environmental conditions
  - Greater removal at the sand soil site at the small MI Dairy site
  - Bioretention basin at small MI dairy site responsible for some removal
  - MSU dairy linear correlation between influent to effluent at MSU site, not at small MI dairy site – what is limiting at the MSU site?

- Maintenance and operation:
  - MSU dairy site = mowing, weeding, and solids removal 2x per year
  - Minimize influent concentrations

- Effective treatment option?
  - Removal percentages for 1 – 1.5 ft are not adequate
  - Final concentrations for BOD and COD are similar to septic tank waste
  - Nitrate concentrations (above 10 mg/L) and metal concentrations show leaching of metals and high concentrations of arsenic

- No correlation for season at MSU dairy or for rainfall at either site with removal percentages or final concentrations
  - Seasonal difference may not hold true for improved operation
Laboratory Soil Column Evaluation of Treatment System - Background

- Primary soil assimilation mechanisms
  - Biological oxidation
  - Adsorption
  - Filtration
- Soil pore water = decreased oxygen = anaerobic conditions
- Aerobic conditions = carbon sources are the electron donors with oxygen accepting the electrons
- Decreased oxygen = anaerobic conditions = changes in electron acceptor
  - Diagenesis model (or electron tower)
  - Ranks by free energy yield per mole of organic carbon oxidized
    - $O_2$, $NO_3^-$, $MnO_2$, $Fe(OH)_3$, $SO_4^{2-}$, and methanogenesis
  - Metal mobilization
- Mn and Fe $\rightarrow$ Reduction mechanisms are biological, physical, or chemical
Laboratory Study Objectives

- Statistically determine the pollutant removal capacity of the volume of the overall soil column system for the various water quality parameters.
- Determine impact of soil depth and total soil volume to pollutant removal.
- Examine the influence of groundwater capillary rise on the depth of soil required for treatment of agricultural runoff.
- Find the degree of treatment variance between two defined soil types, sand and sandy loam, to determine if further detailed analysis is warranted.
Column Design and Operation

- **Three treatments**
  - Depth: 12, 30, & 48 inches
  - Soil: sand and sandy loam
  - Submergence: air or water

- **Vegetation = mixed grass species:**
  - tall fescue (38%), smooth bromegrass (28%), annual ryegrass (20%), reed canarygrass (12%)

- **Loading:**
  - 75 lbs BOD/acre every 3.5 days

- **Wastewater Application**
  - 1.4 L
  - Synthetic (based on BOD theoretical oxygen demand)
  - 2x per week

- **Sample collection**
  - Bi-weekly, influent and effluent

- **Analyze nutrient cycling, oxygen requirements, metal leaching, and comparison of treatment means**
## Soil Column Layout

<table>
<thead>
<tr>
<th>Application</th>
<th>Soil Type</th>
<th>Length (in)</th>
<th>Submergence</th>
<th>Column #'s</th>
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<tbody>
<tr>
<td>Wastewater</td>
<td>Sand</td>
<td>12</td>
<td>Air</td>
<td>12, 25, 26</td>
</tr>
<tr>
<td>Wastewater</td>
<td>Sand</td>
<td>30</td>
<td>Air</td>
<td>1, 7, 20</td>
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<td>Wastewater</td>
<td>Sand</td>
<td>48</td>
<td>Air</td>
<td>3, 19, 24</td>
</tr>
<tr>
<td>Wastewater</td>
<td>Sandy Loam</td>
<td>12</td>
<td>Air</td>
<td>10, 18, 23</td>
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<tr>
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<td>Sandy Loam</td>
<td>30</td>
<td>Air</td>
<td>4, 5, 13</td>
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<td>Sandy Loam</td>
<td>48</td>
<td>Air</td>
<td>14, 15, 17</td>
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<tr>
<td>Water</td>
<td>Sand</td>
<td>30</td>
<td>Air</td>
<td>30</td>
</tr>
<tr>
<td>Water</td>
<td>Sandy Loam</td>
<td>30</td>
<td>Air</td>
<td>22, 29</td>
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<td>Water</td>
<td>2, 11, 21</td>
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<td>30</td>
<td>Water</td>
<td>6, 16, 28</td>
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<tr>
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<td>Sandy Loam</td>
<td>48</td>
<td>Water</td>
<td>8, 9, 27</td>
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</table>
Soil Characteristics

- **Porosity:**
  - Sandy loam 38%
  - Sand 42%
- Oxygen diffusion rates
- Soil moisture
- Flow Rtes

<table>
<thead>
<tr>
<th>Depth (in)</th>
<th>Soil Volume (in³)</th>
<th>Porosity Volume (mL)</th>
<th>Ratio of Wastewater Volume to Pore Space Volume</th>
<th>Sand</th>
<th>Sandy Loam</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand</td>
<td>Sandy Loam</td>
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<tr>
<td>12</td>
<td>339</td>
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<td>30</td>
<td>848</td>
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<td>48</td>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sand</th>
<th>Sandy Loam</th>
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<tr>
<td>pH</td>
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<td>6.9</td>
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<tr>
<td>P (ppm)</td>
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<td>98</td>
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<tr>
<td>K (ppm)</td>
<td>8</td>
<td>133</td>
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<tr>
<td>Ca (ppm)</td>
<td>632</td>
<td>966</td>
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<tr>
<td>Mg (ppm)</td>
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<td>198</td>
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<tr>
<td>Zn (ppm)</td>
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<td>Mn (ppm)</td>
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<tr>
<td>Cu (ppm)</td>
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<td>13.9</td>
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<tr>
<td>Fe (ppm)</td>
<td>8.1</td>
<td>44.7</td>
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<td>Organic Matter (%)</td>
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<td>Chloride (ppm)</td>
<td>61</td>
<td>59</td>
</tr>
<tr>
<td>Total N (ppm)</td>
<td>n.d.</td>
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<tr>
<td>Nitrate-N (ppm)</td>
<td>0.6</td>
<td>11.0</td>
</tr>
<tr>
<td>Ammonium-N (ppm)</td>
<td>0.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Sand (%)</td>
<td>93.5</td>
<td>69.8</td>
</tr>
<tr>
<td>Silt (%)</td>
<td>2.8</td>
<td>25.9</td>
</tr>
<tr>
<td>Clay (%)</td>
<td>3.7</td>
<td>4.3</td>
</tr>
</tbody>
</table>
Results commonly below the detection limit

90-99% removal over 12 inches (except sandy loam submerged), below 30 mg/L surface discharge limit

Statistical difference in soil and depth, and depth*soil interaction

Sand soils no stat difference in depth from 12-48 inches
COD Sand (top) Sandy Loam (bottom)

- 12 inch sand significant difference from 48 inch sand only
- Sand effluent range 0-40 mg/L
- Stat model significant for depth, soil, sub and interactions
- $\text{BOD}_5$/COD ratios indicate incomplete removal of organic material in 12 inch columns
Soil COD

![Graph showing Soil COD levels at different depths. The graph plots COD (mg/kg dry) against Depth (inches). The COD levels decrease significantly with increasing depth. There are four lines representing different treatments: 30 - S, 12 - S, 30 - S, and 48 - S. Each line shows a decline in COD levels as depth increases.]
TKN Sand (top) Sandy Loam (bottom)

- Stat significance for depth and soil and interactions
- Significant difference in all depths for sandy loam, only for 12 inch in sand
- Increased contact time for microbial degradation in longer columns
- Increased microbial ammonification rates in aerobic conditions
- Significant differences in all depths for submergence
Ammonia Sand (top) Sandy Loam (bottom)

- Optimal conditions for nitrification (pH, carbon source, temp), dependent on aeration
- Typical surface discharge is 8 mg/L-N, except 12 inch sandy loam columns
- Significant difference for depth and soil and interactions
- 12 inch sand performs similarly to 30 and 48 inch sandy loam columns
Nitrate Sand (top) Sandy Loam (bottom)

- All effluent concentrations are over the 10 mg/L drinking water standard
- Denitrification inhibited by oxygen, requires soil moisture of 60-90% (organic carbon available)
- Stat difference in soil and between 12 inch and 30 & 48 inch sand columns and all depths of sandy loam columns, and main effect for submergence
Initial Mn sandy loam concentrations are 3x sand soils

Significance for all depths, soil and sub

No interactions effects

Average effluent values (by increasing depth):

- Sand: 109 ug/L, 5 ug/L, and 7 ug/L,
- Sandy loam: 290 ug/L, 150 ug/L, and 37 ug/L,
- Sub: 608 mg/L, 304 ug/L, and 256 ug/L
Mn Soil Concentrations by Depth

![Graph showing Mn soil concentrations by depth](image-url)
Laboratory Soil Column Evaluation of Treatment System

- Statistically determine the pollutant removal capacity of the volume of the overall soil column system for the various water quality parameters.
- Determine impact of soil depth and total soil volume to pollutant removal.
- Examine the influence of groundwater capillary rise on the depth of soil required for treatment of agricultural runoff.
- Find the degree of treatment variance between two defined soil types, sand and sandy loam, to determine if further detailed analysis is warranted.
Laboratory Soil Column Evaluation of Treatment System

- Significant difference for pollutant effluent concentrations:
  - Depth of 12 inches to those of greater depth
  - Soil type (except for alkalinity)
  - Submergence for Mn, Alkalinity, Nitrate, and COD
  - Interaction effects depth*soil and depth*submergence

- Depth performance: increase in depth = increase in treatment, up to 90% removal for many parameters at a depth over 12 inches

- Submerged columns typically had decreased removal performances

- Sand soil had greater pollutant removal percentages than sandy loam soils for almost all parameters
  - Sandy loam soils also had significant increases in Mn leaching
  - Soil physical properties have a significant impact on soil moisture and oxygen availability
    - high porosity, = high oxygen diffusion rate
  - Oxygen availability was theorized to be rate limiting in the nitrification process
Field and Laboratory Scale Comparison

- Similar trends for columns and field data
- Differences in the results can be explained by the experimental conditions
  - Higher treatment removal percentages are a result of the greater pollutant loadings
  - The MSU filter strips had a significant increase in soil clay content, reducing oxygen concentrations and impacting removal
  - Leaching of metals indicated anaerobic conditions within the field
  - As with sandy loam soils, the 12 inch sand columns had on average greater removal percentages than the filter strips at the small MI dairy site
Conclusions

- Manure produced the greatest concentrations of COD, BOD$_5$, ammonia, TKN, SO$_4$$^-$$^-$, solids, TOC, and Cl$^-$
- Average pollutant concentrations: feed sources < manure sources
  - due to large surface area (quantity) 29% of the drainage area,
- Average concentrations from feed were too great for treatment using agricultural filter strips
- Low pH values between 4 and 5 from feed sources impede biological treatment and burned the vegetation
- Water QUANTITY and dilution proved to be the determining factor in pollutant loading and allocation of management practices
- Management practices:
  - Proper upright silage filling practices
  - Bunker silos need to be covered and swept prior to precipitation and feed faces need to be maintained
  - If manure is a larger component than in this study, covering the manure prior to precipitation events or providing barriers such as berms or curbs can limit the transport of pollutants
Conclusions (con’t)

- Sand soils have greater performance than sandy loam soils for a number of parameters
  - Increase in water holding capacity decreases oxygen diffusion
  - Backfilling filter strips with higher porosity soils can increase treatment of many parameters or potentially mechanically increasing soil porosity, or selecting vegetation that can increase oxygen diffusion and porosity

- BOD$_5$ removal requires a minimum depth of 30 inches for sand and sandy loam soils to reach a concentration below 30 mg/L
  - If groundwater is present within the system, it is recommended that the depth be increased to 48 inches
  - Appropriate site selection for filter strips at increased depth to groundwater will reduce groundwater impact.

- COD removal requires a minimum depth of 30 inches
  - BOD$_5$/COD ratios that indicate incomplete removal of biodegradable material in 12 inch columns.
Conclusions (con’t)

- Removal of TKN and ammonia rely on nitrification and require 30 inches of treatment depth in sand and 30 inch soils but realize an even greater removal in 48 inch soils.
  - Nitrification rates are controlled by alkalinity availability, pH, temperature, and oxygen availability
  - Soils produce an excess of alkalinity and remain between the optimum pH, so if temperatures can be maintained between 5°C and 40°C, nitrification is based solely on oxygen
  - Increase oxygen within the treatment system to increase nitrification
- Potential implementation implications with nitrate and metal leaching
Future Research

- Evaluating nitrite build-up, including possible toxicity
- Dual soil treatment system (aerobic and anaerobic zone)
  - Possibilities include a defined clay layer to provide an anaerobic zone after aerobic treatment
- Measurement of dissolved oxygen under various treatment conditions
- Impact of soil moisture on pollutant removal
- Assessment of metal compounds (oxidation state)
- Life cycle of soil in terms of metal adsorption
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Thank You

Becky Larson
ralarson2@wisc.edu
(608) 890-3171