Impact of drying-rewetting cycles on nitrate removal rates in woodchip bioreactors

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What are woodchip bioreactors?

- Agricultural BMP
- Intercept tile drainage
- Targets nitrate removal
- ~20 year lifespan
- NRCS approved
- 2-22 g N m⁻³ d⁻¹ in field
- Mainly seen in Midwest
What are drying-rewetting cycles?

- Cycle between dry/wet conditions
- Gradient of conditions

<table>
<thead>
<tr>
<th>Dry</th>
<th>Unsaturated</th>
<th>Wet</th>
<th>Saturated</th>
</tr>
</thead>
</table>

- Based on literature:
  - Stimulates respiration
  - Increases mineralization of C & N
  - Changes in microbial community

Experimental Hypothesis

Do drying-rewetting cycles in woodchip bioreactors significantly improve treatment performance by increasing nitrate removal rates?

- denitrification...
- + Carbon
- Aerobic breakdown increases available carbon
- DENITRIFICATION!!!
Methods

- Lab experiment with 8 woodchip-filled columns
- Continuous upflow (~8 hr HRT) for 10 months
- Two treatment groups
  - DRW – Drained once a week, unsaturated for 8 hr
  - SAT – Continuously saturated

High frequency water chemistry measurements

- Multi-point sampler coupled with spectrophotometer to measure column outflow (Birgand et al., 2016; Maxwell et al., 2018)
- Measurements for NO3 and dissolved organic carbon (DOC)
- Measurements were made every 2 hr. on each column and stock tank for 165 of 304 days
**Statistical Methods**

- Compared volumetric removal rates (g N/m$^3$/d) to normalize by flow
- Separated data into weekly periods, based on weekly DRW events
- SAS proc mixed to test significance of treatment effect in a mixed linear model
  - Repeated measures, account for autocorrelation
- Developed local calibration for spectrophotometer using partial least-squared regression (PLSR) methods

**Results : High frequency data**

84 measurements per column per week
Results: High frequency data
84 measurements per column per week

![Graph showing NO₃ concentration over time for different treatments.](image)

Results: High frequency data
640 measurements per week for all columns

![Graph showing NO₃ concentration over time for different treatments.](image)
Results: High frequency data
10,000 measurements over 300 days for all columns

Results: Mean volumetric removal rates for treatment groups, by period

<table>
<thead>
<tr>
<th></th>
<th>DRW Volumetric Rate (g N/m²/d)</th>
<th>SAT Volumetric Rate (g N/m²/d)</th>
<th>Difference in Means (s.d.)</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 0a</td>
<td>5.62</td>
<td>5.02</td>
<td>0.60 (0.28)</td>
<td>0 - 7</td>
</tr>
<tr>
<td>Period 0b</td>
<td>5.14</td>
<td>5.22</td>
<td>-0.082 (0.17)</td>
<td>7 - 14</td>
</tr>
<tr>
<td>Period 0c</td>
<td>14.50</td>
<td>14.99</td>
<td>-0.49 (0.34)</td>
<td>14 - 21</td>
</tr>
<tr>
<td>Period 1</td>
<td>20.51</td>
<td>20.82</td>
<td>-0.28 (0.34)</td>
<td>21 - 28</td>
</tr>
<tr>
<td>Period 2</td>
<td>25.38</td>
<td>23.79</td>
<td>1.59 (0.37)</td>
<td>28 - 35</td>
</tr>
<tr>
<td>Period 3</td>
<td>24.91</td>
<td>21.49</td>
<td>3.42 (0.25)</td>
<td>35 - 42</td>
</tr>
<tr>
<td>Period 4</td>
<td>23.80</td>
<td>18.77</td>
<td>5.03 (0.40)</td>
<td>42 - 49</td>
</tr>
<tr>
<td>Period 5</td>
<td>16.96</td>
<td>14.14</td>
<td>2.82 (0.23)</td>
<td>49 - 56</td>
</tr>
<tr>
<td>Period 6</td>
<td>15.18</td>
<td>12.94</td>
<td>2.24 (0.19)</td>
<td>56 - 63</td>
</tr>
<tr>
<td>Period 7</td>
<td>16.57</td>
<td>13.16</td>
<td>3.41 (0.26)</td>
<td>63 - 70</td>
</tr>
<tr>
<td>Period 8</td>
<td>22.02</td>
<td>16.09</td>
<td>5.93 (0.45)</td>
<td>70 - 77</td>
</tr>
<tr>
<td>Period 9</td>
<td>17.01</td>
<td>12.60</td>
<td>4.41 (0.37)</td>
<td>77 - 84</td>
</tr>
<tr>
<td>Period 10</td>
<td>13.07</td>
<td>9.71</td>
<td>3.36 (0.36)</td>
<td>84 - 91</td>
</tr>
<tr>
<td>Period 11</td>
<td>18.13</td>
<td>13.38</td>
<td>4.75 (0.36)</td>
<td>91 - 98</td>
</tr>
<tr>
<td>Period 12</td>
<td>11.96</td>
<td>8.35</td>
<td>3.60 (0.11)</td>
<td>147 - 154</td>
</tr>
<tr>
<td>Period 13</td>
<td>12.07</td>
<td>8.42</td>
<td>3.64 (0.11)</td>
<td>154 - 161</td>
</tr>
<tr>
<td>Period 21</td>
<td>10.92</td>
<td>7.63</td>
<td>3.29 (0.11)</td>
<td>161 - 168</td>
</tr>
<tr>
<td>Period 22**</td>
<td>14.22</td>
<td>7.88</td>
<td>6.34 (0.20)</td>
<td>168 - 171</td>
</tr>
<tr>
<td>Period 35</td>
<td>11.43</td>
<td>8.05</td>
<td>3.38 (0.13)</td>
<td>258 - 259</td>
</tr>
<tr>
<td>Period 36</td>
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<td>3.13 (0.12)</td>
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</tr>
<tr>
<td>Period 37</td>
<td>13.24</td>
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<td>3.70 (0.13)</td>
<td>266 - 273</td>
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<tr>
<td>Period 38</td>
<td>12.67</td>
<td>9.30</td>
<td>3.37 (0.12)</td>
<td>273 - 280</td>
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<tr>
<td>Period 39</td>
<td>12.06</td>
<td>8.82</td>
<td>3.24 (0.13)</td>
<td>280 - 287</td>
</tr>
</tbody>
</table>

After the second weekly DRW event, removal rates in DRW columns were significantly greater in all periods.
Nitrate response to DRW cycles

Removal rates in DRW columns decreased quickly within 3 days of rewetting, but were still significantly higher 7 days later.

Does DOC production explain NO3 removal?

DOC production (leaching) rates decreased with nitrate removal after rewetting.
Does DOC production explain NO3 removal?

Days 20 - 100

DOC production (leaching) rates explained most of variance in removal ($R^2 : 0.90 – 0.97$)

Does DOC production explain NO3 removal?

Days 140 - 180

DOC production (leaching) rates explained most of variance in removal ($R^2 : 0.90 – 0.97$)
Does DOC production explain NO3 removal?

DOC production (leaching) rates explained most of variance in removal ($R^2 : 0.90 – 0.97$)

Does temperature affect treatment effect?

Difference in group removal rates were fairly consistent over the experiment, and appears to be an interaction effect with temperature
Results: ANOVA Analysis

- Model best fitted by AR(1) covariance structure
- Treatment effect is significant: 3.36 g N/m^3/d
- Estimate of treatment is roughly equal to difference in group means over the experiment

<table>
<thead>
<tr>
<th>Covariance Parameter Estimates</th>
<th>Solution for Fixed Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cov Parm</td>
<td>Subject</td>
</tr>
<tr>
<td>AR(1)</td>
<td>Column</td>
</tr>
<tr>
<td>Residual</td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>1</td>
</tr>
</tbody>
</table>

Results: Microbial analysis

Distinct differences in microbial communities after only 4 drying/rewetting events
Experiment Conclusions

- Drying-rewetting cycles increased nitrate removal rates in woodchip bioreactors by 30-80%
- Aerobically-produced DOC is the most likely cause
- Increased removal even after 39 DRW cycles
- Most dramatic increases within 1-3 days of rewetting
- Microbial community shift

Broader Conclusions

- Bioreactor performance can be improved through design/management
- Implications for management of other carbon-substrate BMPs (i.e. wetlands)
- DOC availability and microbial community results could explain high productivity of other dry/wet landscapes (i.e. riparian zones, saturated buffers)
Acknowledgements

Funding Source

Facilities and Lab Analysis

Microbial Analysis

Results: Flow and temperature

![Graphs showing flow rate and temperature over time with different treatments.]
Results: Calibration of spectrophotometer

**NO3**
- $R^2 > 0.99$
- $RMSEP < 0.30 \text{ mg/L}$

**DOC**
- $R^2 : 0.56 – 0.96$
- $RMSEP < 0.25 \text{ mg/L}$

Good fit, reliable data!