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Matthew J. Helmers
Iowa State University, mhelmers@iastate.edu

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Cover crops, bioreactors, and wetlands for nitrate reduction
Matthew J. Helmers, Professor, Agricultural and Biosystems Engineering, Iowa State University

Introduction
With the release of the Iowa Nutrient Reduction Strategy in early 2013 there has been increased interest in what practices can be utilized by farmers to reduce nutrient export to downstream water bodies. As highlighted by the ISU Extension and Outreach Special Publication 235 (2013) there are many in-field, land use, and edge-of-field practices that have potential to reduce nutrient export. Three practices that have garnered a substantial amount of interest are cover crops, bioreactors, and wetlands. These three practices span the scale from in-field (cover crops) to edge-of-field (bioreactors) to watershed scale (wetlands).

Cover crops
From 2006-2013, the impact of a winter cereal rye cover crop on nitrate-N concentrations in subsurface drainage were studied at a site near Gilmore City, Iowa (Lawlor et al., 2008). For this study the winter cereal rye was drilled after harvest of the cash crop and terminated with Glyphosate in the spring approximately two weeks before corn planting and a day or two before soybean planting. Nitrogen was applied in early June each year as injected aqua-ammonia (125 lb-N/acre from 2006-2009 and 150 lb-N/acre from 2010-2013). The rye biomass (Figure 1) and nitrogen uptake (Figure 2) varied depending on growing conditions, but was always greater before soybeans since the rye was allowed to grow longer. Overall, the annual flow-weighted nitrate-N concentrations were reduced from the treatments that included the cover crops (Figure 3). The average reduction was approximately 20% when the rye was grown before corn and 27% when the rye was grown before soybeans. Kaspar et al. (2007) also summarized the performance of a winter central rye cover near Ames, IA. Their study documented a nitrate-N concentration reduction of approximately 60% when winter cereal rye cover crop was used. The difference in cover crop performance highlight that the nitrate-N reduction is likely to vary depending on site and climatic conditions. This highlights the need for additional studies documenting the performance of cover crops.

Figure 1. Above ground rye biomass at Gilmore City from 2006-2012.
Bioreactors

A woodchip bioreactor is made by routing drainage water through a buried trench filled with woodchips (Figure 4). Woodchip bioreactors also are known as denitrification bioreactors, a name that is slightly more descriptive of the actual process occurring inside the bioreactor. Denitrification is the conversion of nitrate (NO$_3^-$) to nitrogen gas (dinitrogen, N$_2$) that is carried out by bacteria living in soils all over the world and also in the bioreactor. These good bacteria, called denitrifiers, use the carbon in the woodchips as their food and use the nitrate as part of their respiration process. Because these bacteria also can breathe oxygen, providing anaerobic conditions through more constantly flowing tile water helps ensure that the bacteria utilize the nitrate.

Most installations in Iowa to date have been approximately 100 to 120 feet long and 10 to 25 feet wide. Typically, no land is taken out of production for a bioreactor. Because bioreactors tend to have an orientation that is long and narrow, they fit well in edge-of-field buffer strips and grassed areas.
Results from three field-scale bioreactors in Iowa has been summarized by Christianson et al. (2012). The size of these bioreactors are shown in Table 1. Performance of these bioreactors are shown in Table 2.

**Table 1. Size of bioreactors studied by Christianson et al. (2012)**

<table>
<thead>
<tr>
<th>Bioreactor</th>
<th>Location</th>
<th>Date of Installation</th>
<th>Drainage Treatment Area (acre)</th>
<th>Length (ft)</th>
<th>Width (ft)</th>
<th>Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NERF</td>
<td>Northeast Iowa</td>
<td>April 2009</td>
<td>46.6</td>
<td>87.3</td>
<td>15.1 top, 7.9 bottom</td>
<td>3.3</td>
</tr>
<tr>
<td>Greene Co.</td>
<td>Central Iowa</td>
<td>August 2008</td>
<td>62.3</td>
<td>49.9</td>
<td>24.9</td>
<td>3.6</td>
</tr>
<tr>
<td>Hamilton Co.</td>
<td>Central Iowa</td>
<td>June 2009</td>
<td>66.3</td>
<td>100.1</td>
<td>12.1</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Table 2. Performance of three field-scale bioreactors studies by Christianson et al. (2012)**

<table>
<thead>
<tr>
<th>Bioreactor</th>
<th>Mean annual bioreactor concentration reduction</th>
<th>Mean annual bioreactor load reduction</th>
<th>Percent of water treated</th>
<th>Mean annual total load reduction including bypass flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>NERF</td>
<td>12%-16%</td>
<td>12%-15%</td>
<td>91%-99%</td>
<td>12%-14%</td>
</tr>
<tr>
<td>Greene Co.</td>
<td>38%-61%</td>
<td>46%-68%</td>
<td>51%-68%</td>
<td>27%-33%</td>
</tr>
<tr>
<td>Hamilton Co.</td>
<td>79%-81%</td>
<td>74%-76%</td>
<td>73%-87%</td>
<td>49%-57%</td>
</tr>
</tbody>
</table>

**Wetlands**

The processes involved in nitrogen transformation in wetlands are comparable to those in other aquatic systems and soils. Under anaerobic conditions, NO$_3^-$ can serve as a terminal electron acceptor for the oxidation of organic carbon either through denitrification, resulting in gaseous losses of N$_2$O or N$_2$, or through dissimilatory reduction of nitrate to ammonium (Bowden, 1987). Relatively low rates of denitrification and dissimilatory nitrate reduction are observed in natural, unpolluted wetlands (Seitzinger, 1988). However, when wetlands are subjected to significant external nitrate loading, relatively high rates of denitrification can be expected, and with rare exception, denitrification is cited as the primary reason wetlands serve as nitrogen sinks. The effectiveness of wetlands in reducing nitrogen export from agricultural fields will depend on the magnitude and timing of nitrate loads and the capacity of the wetlands to remove nitrate by denitrification.

The effectiveness of wetlands in reducing agricultural nutrient loads is influenced by a range of climatological and site-specific factors. Important factors related to wetland inputs include the timing and magnitude of nutrient and...
hydrologic loads to the wetland, the extent of subsurface tile drainage, the concentrations of nutrients entering the wetland, and the chemical characteristics of nutrients entering the wetland (for example, dissolved versus particulate fractions, nitrate versus ammonium and organic nitrogen). Maximum percent reduction in nutrients occurs when residence time is greatest and hydraulic loading rates are low (Figure 5). In the case of nitrate, flood water that transports a large nitrate load rapidly through an otherwise effective wetland may show relatively low percent reductions in nitrate, even though the wetland may be removing a significant mass of nitrate. In the case of nitrogen associated with suspended particles, both percent loss and mass loss rates can be high during periods of high hydrologic loading and short residence times.

Figure 5. Wetland nitrate removal efficiencies versus hydraulic loading rate and retention time for wetlands monitored from 2004-2010. The lines show estimated average percent removal and 95% upper and low prediction bounds (Crumpton et al., in review)

The nitrate removal efficiencies shown in Figure 5 are from Iowa Conservation Reserve Enhancement Program (CREP) wetlands that have been monitored by Dr. William Crumpton at Iowa State University. These wetlands span the 0.5% - 2.0% wetland/watershed area ratio range approved for Iowa CREP wetlands. From monitoring data, when the wetland/watershed area ratio averages approximately 1%, the long-term nitrate removal has been shown to be approximately 52%.

Conclusions
Reducing nutrient movement to downstream water bodies is likely to become increasingly critical in the years ahead. The Iowa Nutrient Reduction Strategy Non-Point Source Science Assessment identified many practices that could be used to reduce nutrient loading. Three practices that show great potential are cover crops, bioreactors, and wetlands. These practices would be positioned at different locations within the agricultural landscape but all have potential to reduce downstream nitrate loss. The performance of these practice will vary depending on climatic factors. Design and the performance of these practices should continue to be evaluated.

References

