Nitrate removal, flow paths, and N_2O emissions in two denitrifying woodchip bioreactors: Mitigating agricultural nutrient loads in the Salinas Valley, CA

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Background

Plants require nitrogen to grow, and therefore multiple types of synthetic and organic nitrogen fertilizers exist to increase biomass over the course of a growing season. Nitrate is an aqueous nitrogen species found in fertilizer or converted from ammonium fertilizers by soil bacteria.

Nitrate is an ubiquitous groundwater contaminant; agricultural fertilizers, sewage treatment, and dairy operations are often the most sizeable contributors (Pye et al. 1983; Keeney 1986). In California, a study that included four of the five counties with the largest agricultural production, 96% of human-generated nitrate sources to ground water were attributed to cropland. The same study documented that over 30 community public (>14 connections) and state small (5-14 connections) water systems are already over the U.S. EPA Maximum Contaminant Level of 10 mg L^{-1} Nitrate-N in the Salinas River watershed alone, with a few over 20 mg L^{-1} N and many more approaching that limit (Harter et al. 2012).

Fertilizer management is important for preventing nitrate loading, but post-farm mitigation is also essential to treating the nitrate that remains in irrigation runoff. Of treatment options, on-farm or plume-level is touted as the most cost-effective, by several orders of magnitude compared to pump-and-treat (Harter et al. 2012).

Denitrifying filters and bioreactors have been used to remove nitrate from end-of-pipe industrial waste and landfill sites (He et al. 2007; Morita et al. 2007). Studies also showed that denitrification occurred naturally in shallow aquifers, with a direct correlation to the presence of labile organic carbon (Starr and Gillham 1993). Starting in the early 1990s, sawdust and woodchip denitrifying barriers were designed that removed nitrate from septic systems, agricultural fields, and tributary streams; a later design is pictured in Figure 1 (Robertson and Cherry 1995; Schipper et al. 2010).

One potential downside to woodchip bioreactor function is that while complete denitrification results in N_2 production, partial denitrification can also occur and produce nitrous oxide (N_2O) under some conditions (Weir et al. 1998). N_2O is a potent greenhouse gas for which agriculture is a large contributor. Generally, low levels of surface and dissolved N_2O emissions have been observed in bench-scale and field woodchip bioreactor measurements; however, more studies are needed (Greenan et al. 2009; Woli et al. 2010; Schipper et al. 2010).

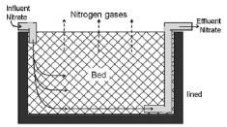

Figure 1. Diagram of denitrifying bed. Woodchip media act as a carbon source for microbial respiration that couples nitrate as an electron acceptor and converts it into harmless dinitrogen (N_2) gas, which composes 78% of the atmosphere. Denitrification is considered the most permanent mechanism for removing nitrate so it does not leach into groundwater, flow off into nearby drainage ditches and be lost in surface flows, or become converted into ammonium with other subsequent pathways. Figure source: Schipper et al. 2010.

Purpose

My project is focused on the internal dynamics of two woodchip denitrifying bioreactors. A tracer test has been conducted and nitrate (NO_3^-)and dissolved organic carbon (DOC) levels measured to be used to determine parameters related to nitrate removal efficiency. N_2O emissions will also be measured and assessed to confirm low levels of greenhouse gas production.

Site Description

The two bioreactors are located on farms in the Salinas Valley, California. One receives nitrate loads from tile drain irrigation waters while the other receives only surface runoff, the latter of which is consistently several degrees warmer. Nitrate loads in irrigation runoff from both farms are never limiting to denitrification during the growing season for those farms. The tile drain-receiving bioreactor was installed in April 2011 and the surface-receiving bioreactor in May 2012; woodchips are partially replenished annually due to decomposition. Lettuce appears to be the primary crop planted on adjacent fields where irrigation waters directed to both bioreactors source from during the sampling period.

Hypotheses

Tracer test

Null hypothesis: Hydraulic efficiency (e_V) equal to 1;

Alternative hypothesis: Hydraulic efficiency (e_V) less than 1;

where hydraulic efficiency is defined as:

$$\frac{\text{hydraulic retention time determined by tracer test}}{\text{intended hydraulic retention time}}.$$

N_2O emissions

Dissolved N_2O emissions are predicted to be less than or equal to IPCC emissions factor for indirect N_2O emissions from leaching and runoff (EF5) is 0.0075 kg N_2O-N/kg N input (IPCC 2006).

Methods

Flow patterns will be assessed by conducting a tracer test, which will provide a confirmation of actual versus the intended two-day hydraulic retention time (HRT), information on how laminar or mixed the flow is, and a comparison of retention time in the first half and second half of the bioreactor. Flow patterns will also be compared to nitrate removal data.

N_2O emissions will be measured over the course of one growing season, including both dissolved and surface emissions. These measurements will be compared to expected ambient levels, Intergovernmental Panel on Climate Change (IPCC) predicted dissolved N_2O emission factors that are based on nitrate levels, and surface to dissolved N_2O ratios.

Completed:

- ✓ First sodium bromide (NaBr) tracer test and simultaneous nitrate sample collection (field test) (Methods: Kadlec and Wallace 2009)
- ✓ 2012 NO_3^- and DOC sampling at tile-drain bioreactor

Scheduled:

- ✓ Tracer test analysis

  Objectives:
  - Calculate mean residence time of the tracer and hydraulic efficiency (important for optimizing denitrification)
  - Estimate V_p, the pore volume swept by the tracer
  - A F-C diagram (flow-capacity)
  - Create a breakthrough curve based on data
  - Qualitative analysis of a cross-section approximately at the midpoint of the bioreactor (Shook et al. 2004; Kadlec and Wallace 2009)
- ✓ Surface N_2O emissions
  - Measured using gas sampling vented chambers (Woli et al. 2010)
- ✓ Dissolved N_2O emissions
  - Draw water samples with a 50-mL glass syringe and fill half with an inert gas, shake for one minute, then take 20-mL gas sample from the headspace (Kazunori et al. 2010)

Preliminary Data

NO_3^- and DOC data from five intervals along the length of one bioreactor at two depth intervals were analyzed from weekly sampling last August and September, and there appears to a very close to significant difference between the two foot and three foot depths for nitrate (mean difference of 4.3 ppm, p=0.06). In addition nitrate removal appears to be greatest within the first half along the length of the bioreactor, with average removal rates appearing lower after the monitoring well at 24', despite lack of any nitrate limitation (Fig. 2).

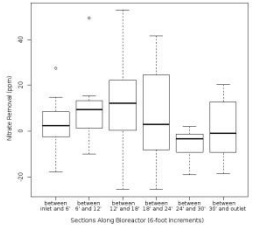

Figure 2. Nitrate removal rates at 6-foot intervals from bioreactor inlet with data from twelve sampling dates.

Acknowledgements

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