Passive Biological Treatment Systems for Denitrification of Tile-Drain Effluent

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We are interested in finding operators who are willing to install these technologies to test their function in full-scale operation. Please contact us (below) if you are interested in hosting such a project, have suggestions for us, or if you want more information on system design and function.

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NITRATE REMOVAL
FROM TILE DRAIN OUTFLOWS

1. INTRODUCTION

Tile drain water contains high concentrations of nitrate. Regional Water Quality Control Boards are regulating Nitrate under a TMDL. A number of passive treatment processes exist to reduce nitrate concentrations. If you have a tile drain system on your fields, this treatment may be easier than you think. A description of the process and basic design elements of *passive* nitrate treatment systems are described in this guide. Cost estimates are available in the accompanying pamphlet "Denitrification of tile-drain effluent: Technology Summary"

Denitrification

Nitrate is converted to atmospheric nitrogen gas by bacteria in a process called denitrification. To carry out the reaction, these bacteria need a source of organic carbon. These bacteria don't breathe oxygen like we do; in fact, the presence of oxygen will inhibit the denitrification reaction. Instead, they accomplish respiration using nitrate and exhale nitrogen gas. Nitrogen gas is harmless and already makes up 78% of the atmosphere.

Anoxic Reactors

To get them to work, you need to provide the proper environment for these bacteria, but it has to be *anoxic*, meaning there's no oxygen. We can create an anoxic environment easily with a bed of submerged woodchips, which also serve as the carbon source. If we create the right environmental conditions and provide nitrate, denitrifying bacteria will establish spontaneously. We create these environmental conditions in a *reactor*. A reactor is a treatment basin designed to reduce the concentration of one or more pollutants or nutrients. The size of the reactor depends on the concentration of the pollutant in the drainage, the flow rate of the water to be treated, the desired final concentration of the pollutant, and the water temperature.

Just to get it out of the way, the reactor will not take up a lot of land area. As shown on Figure 1, a typical woodchip reactor for the removal of 11 kg nitrate-N/d (i.e., 20 gal/min at 100 mg nitrate-N/L) will be about 1 tenth of 1 percent of the land area it is designed to deal with, assuming it is about 4 feet deep. If you can make it deeper, it can have a smaller footprint because the reactor size is based on woodchip volume. One potential problem with deeper reactors is the presence of a high water table that may cause problems when installing the liner and other system components.

Other Considerations

Tile drains typically feed a collector pipe, which drains into a basin or tank, called a sump. The reactor can be located to intercept the flow from the collector pipe before or after your sump. Because the sump is usually drained by a pump, the simplest approach is to pipe the discharge from the pump to the reactor inlet. The outlet from the reactor is then piped to the drainage ditch or other discharge location.

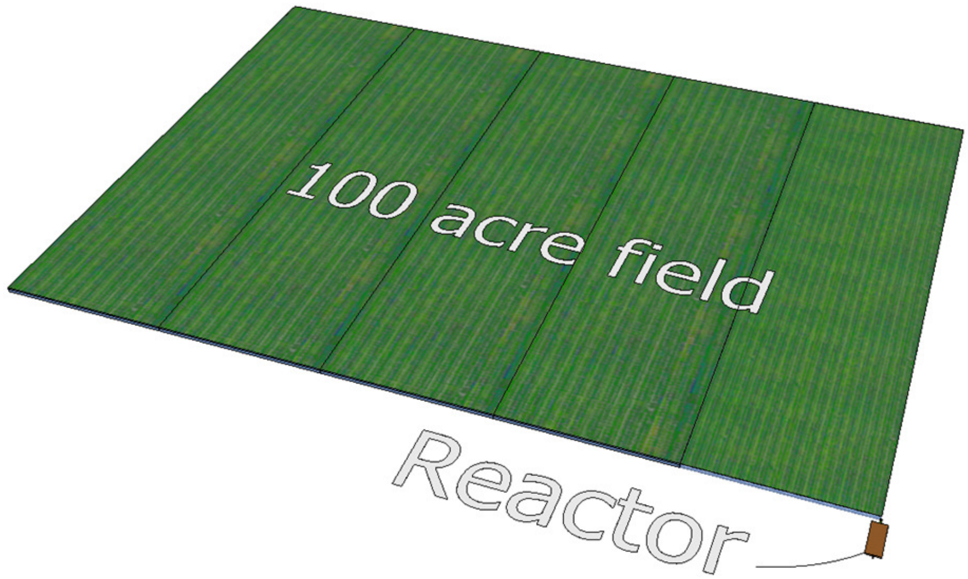

Figure 1: Scale illustration of typical reactor size for a 100 ac field

During process startup, tannins will leach from the wood chips for 2 to 3 months (depends on type of wood used). This results in a brown tint to the water and an increase in the dissolved carbon content, but should be harmless when diluted with the drainage water. Ideally, the water at the drainage outlet would cascade over rocks to re-oxygenate the water and oxidize a portion of the dissolved carbon on its way to the environment.

2. AT-GRADE REACTOR DESIGN BASICS

The simplest design and installation for an anoxic reactor is a 4 foot deep basin lined with a heavy-duty pond liner and filled with woodchips (see Figure 2). The reactor has one inflow from the sump and one outflow to a ditch. The inflow comes into the top of the reactor at one end, the outflow leaves from the bottom of the reactor at the other end but the water level is maintained with an adjustable standpipe. The standpipe is adjusted so that the water level in the reactor stays at about 0.5 ft below the surface of the woodchips. The standpipe can be lowered such that the basin can be drained if needed.

Longevity is an important consideration. We expect the woodchips to last at least 10 years before the reactor needs to be repacked with new chips. The reason for the uncertainty is that the longest-running anoxic woodchip reactors in service are about 10 years old and have not reached the end of their useful life yet. At about $10 per yard, for a 400 cubic yard reactor, that's a cost of $4000 per ten years. It would be suitable to use local materials if there is a local source of wood that is available. It would also be possible to reconfigure the reactor to use materials such as straw, sawdust, or other readily biodegradable substances that have a high reaction rate, including leftover field trash such as sunflower or corn stalks.

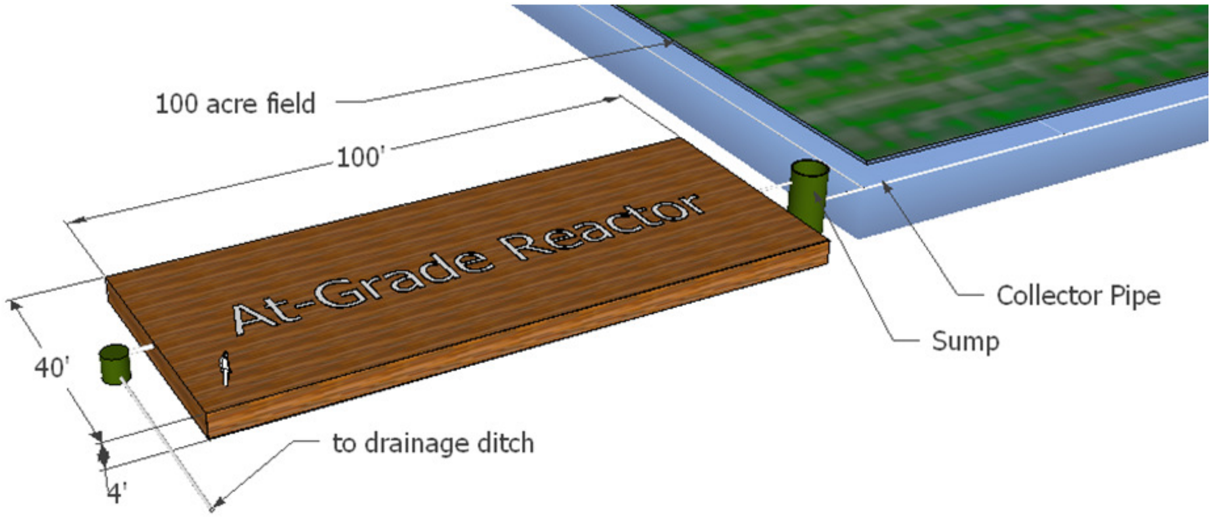

Figure 2: Typical at-grade reactor for a 100-acre field

3. SIZING

The reactor has to be large enough that the *contact time* is long enough for the bacteria in the wood chips to do their job. The contact time required depends on the rate of flow of water from your field, the concentration of nitrate in the water coming from your field, and the temperature. Higher mass removal (flow rate times change in concentration) requirements will result in a larger reactor (i.e., longer contact time). Increased temperatures means a smaller reactor (shorter contact time), because the bacteria are more active when they are warm.

The sizing chart shown on Figure 3 is based on the mass removal of nitrate and minimum daily average drainage water temperature. Mass removal refers to the amount (mass) of removed nitrate required to maintain the concentration you are trying to achieve. It is a simple calculation based on the amount of nitrate coming into the reactor and the desired amount flowing out of the reactor. For example, if the influent concentration is 100 mg nitrate-N/L, the desired concentration of the outflow from the reactor is 10 mg nitrate-N/L (i.e., drinking water standard), and the flow from the field is 20 gal/min (typical for a 100 acre tile drain system), the mass removal can be computed as follows.

Nitrate mass removal = flow rate x change in concentration =

$$[(20 \text{ gal/min})(3.785 \text{ L/gal})(1440 \text{ min/day})] \times [(100 - 10 \text{ mg/L})(10^{-6} \text{ kg/mg})]$$

$$= 9.8 \text{ kg/day}$$

Flow rate can be determined using a bucket and stopwatch from existing drain outlets. The concentration of nitrate (as nitrogen) in your tile drain outflow can be estimated using drinking water or aquarium test kits, but samples should be sent to a certified lab for accurate results.

Call your local UC Cooperative Extension, Natural Resource Conservation Service, or water quality expert to find out how to do this. The lowest daily average temperature of your tile drain outflow can be estimated by repeated measurements using a thermometer in the flow from your sump.

The chart shown on Figure 3 gives the size of reactor required to achieve a given mass removal rate at a given temperature. For a nitrate (as nitrogen) removal rate of about 10 kg/d at a typical temperature of 50 degrees F, a reactor woodchip volume around 450 yd^3 would be required.

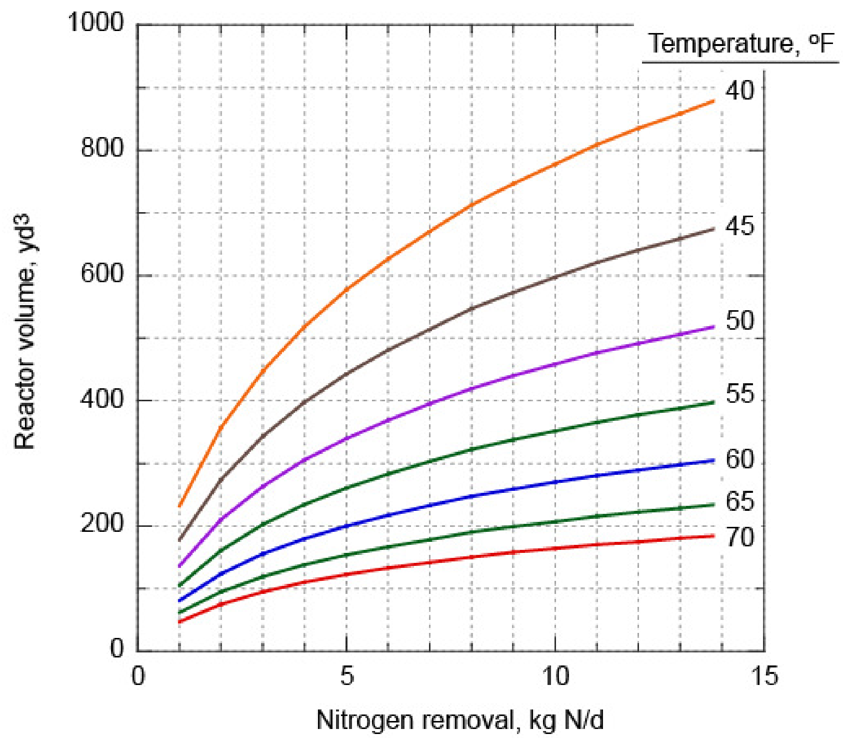

Figure 3: Reactor sizing criteria based on mass removal and temperature

4. AT-GRADE REACTOR DESIGN DETAILS

Now we will discuss some details that maintain the effectiveness of the system, prevent system failure, and possibly save you money and space. It is important that the inflow come in and is equally distributed along the reactor cross-section, not just the top. The goal is to obtain uniform flow through the wood-chip basin starting in the most anoxic region (the bottom). To prevent short-circuiting of the wood chip bed, and also to take advantage of as much of it as possible, you'll need to install a simple manifold in the bottom of the reactor to distribute the water inflow across its width. A check valve or anti-siphon valve may also be necessary to prevent backflow.

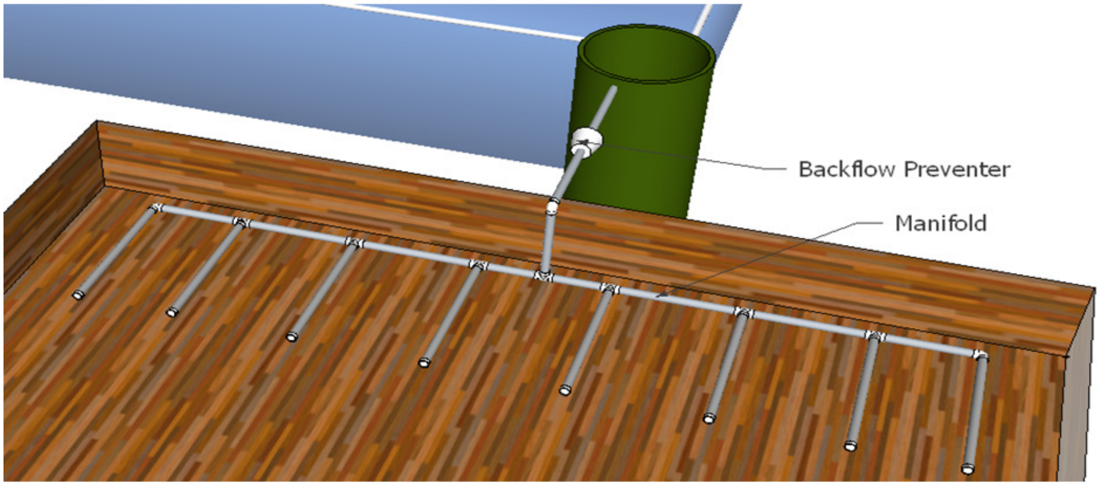

Figure 4: Detailed view of alternate inlet distribution system

A potential benefit of the at-grade Reactor is that you can plant it with rushes, sedges, or other water-loving plants. These plants will take up some nitrate as well, increasing the efficiency of your reactor a small amount. More importantly, you can use them as indicators of the effectiveness of your reactor. The plants will grow poorly or not at all in regions of the reactor that are effectively removing nitrate and the roots will grow into regions where nitrate is present and restrict flow to that area, possibly improving the overall system hydraulics. This diagnostic capability will be useful in managing your reactor.

5. BELOW-GRADE WOOD CHIP REACTOR

Another option is to place the reactor underground entirely. This option will need to be engineered, depending on site specific factors such as surface loads, but the concept is the same as with the at-grade version. The below-grade reactor (see Figure 5) may be more costly, but the result is that you can still use the land it occupies for other purposes. This is expected to be a viable option where available land area is a design constraint.

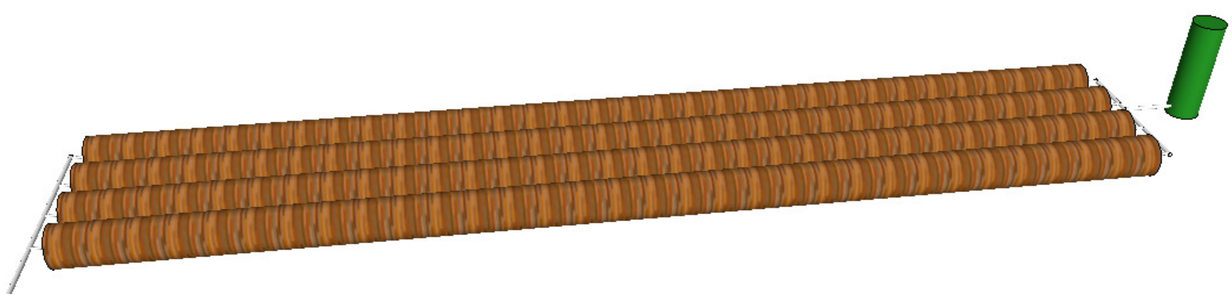

Figure 5: Conceptual below-grade reactor for a 100-acre field

Unlike the at-grade version of the Reactor, this version is completely contained in large tanks, which are buried underground. These tanks could be made from AgBag, culvert, concrete, etc. with reinforcement applied as needed to allow equipment or vehicles to be driven and parked on the ground above the reactors. Sizing is the same as for the at-grade reactor.

6. IN-SITU TREATMENT

This technology has not been tested or engineered yet, but we are working on a proof-of-concept installation currently. The basic idea is that the tile drains themselves are a fine place to do the treatment (see Figure 6), and this saves you space, as well as cost. Money is saved because you don't have to dig a reactor pit or buy and install a liner.

Tile drains are typically installed using a plow or other ditching implement and a special attachment that feeds the tile-drain pipe into the bottom of the ditch. With a little innovation, this setup can be modified to include a trailer with a chute directed at the base of the pipe as it is being laid in place. The chute would carry sawdust or woodchips down to the bottom of the ditch as the pipe is being laid, so that the pipe rests on most of the chips.

A short riser at the end of each tile drain would prevent the groundwater from leaving the pipe until the drain is slightly submerged to keep oxygen out and create an anoxic condition. Note that the specific design will depend on the hydraulic conductivity of your soil.

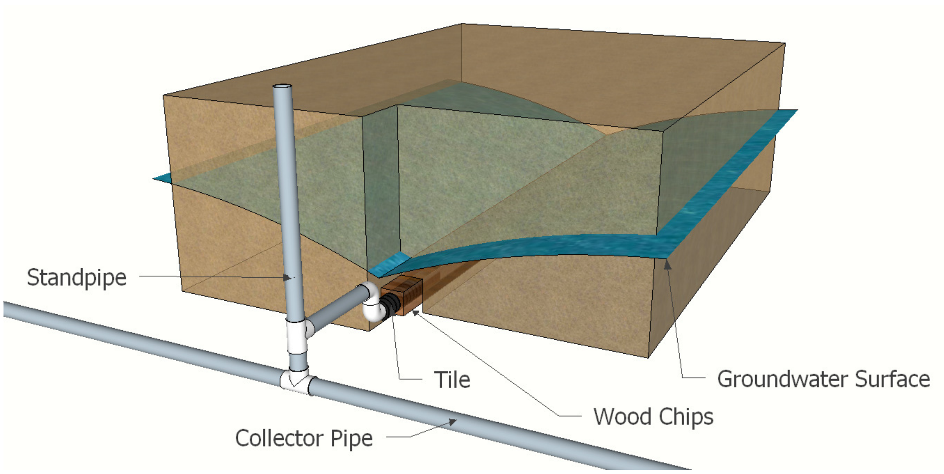

Figure 6: Proposed modified tile drain for *in situ* denitrification

If we assume 40 drains, 500 feet long, per 20 acre field, that is 100,000 feet of Tile Drain for 100 acres. If the ditch is 8 inches wide, and we set the rate of wood chip application so that 2 inches of wood chips covers the bottom of the ditch, we get a total of about 400 cubic yards of woodchips for the whole 100 acre field. That is about the right amount to treat a typical field.

It is unclear at this time what level of Nitrate removal efficiency to expect from this system, but, because it saves space and materials, and possibly reduces operations and maintenance costs, it is be worthy of investigation. In addition, installation techniques will need to be developed.