Project title: Remediation of tile drain water using denitrification bioreactors

Project location: Commercial farms in the central coast region

Project duration: two years

Project leaders:

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CDFA Funding:

Year 1	Year 2	Total
$ 46,986	$ 48,460	$ 95,446

B. Executive summary:

Vegetable production on the Central Coast faces an unprecedented challenge from environmental water quality regulation. The Central Coast Region Water Quality Control Board is adding new monitoring and reporting requirements to this year's renewal of the Conditional Waiver for Irrigated Lands (commonly called the 'Ag Waiver') under which all irrigated agriculture operates. The waiver renewal focuses on nitrate (NO_3-N) pollution abatement; extensive monitoring in recent years has shown that the NO_3-N concentration in surface runoff and tile drain effluent from vegetable fields commonly exceeds the Federal drinking water standard of 10 PPM. While better fertilizer management practices can reduce the NO_3-N load in agricultural wastewater, it is clear that some remediation will also be needed to meet environmental requirements. Of the techniques that have been considered for the remediation of wastewater, biological denitrification appears to be the most promising for treating agricultural runoff and tile drain effluent. This project proposes to field test this technique under commercial field conditions.

Two denitrification bioreactors have recently been constructed on vegetable farms in the Salinas Valley to treat tile drain effluent. A third bioreactor will be constructed in 2012 to treat surface runoff from vegetable fields. All three bioreactors will be managed and monitored throughout the 2012 and 2013 production seasons. The effects of influent

NO_3-N concentration and management practices (hydraulic residence time, and injection of a soluble carbon source to stimulate denitrification) on the rate of denitrification will be determined. The effluent from the bioreactors will be monitored for water quality parameters of environmental importance [NO_3-N, NO_2-N, N_2O (nitrous oxide, a greenhouse gas) and dissolved organic carbon]. Economic analysis will be performed to evaluate the feasibility of employing this technique on a commercial scale. Results of this research will be disseminated to coastal vegetable growers through field day events in both 2012 and 2013, grower educational meetings in 2013 and 2014, and in web-based instructional material hosted on the UCCE websites for Monterey and Santa Cruz Counties.

C. Justification:

Vegetable production on the Central Coast faces an unprecedented challenge from environmental water quality regulation. The Central Coast Region Water Quality Control Board is about to renew the Irrigated Lands Discharge Waiver under which all irrigated agriculture operates. The Waiver renewal focuses on nitrate pollution abatement. It includes new monitoring and reporting requirements, and timetables to comply with nitrate water quality standards. Maintaining surface runoff from vegetable fields below the Federal drinking water standard of 10 PPM NO_3-N presents a challenge, particularly if the irrigation water used is above this nitrate level (as are about 40% of irrigation wells in Monterey County). Extensive monitoring in recent years has shown that runoff NO_3-N closely mirrors the irrigation water source, and that common conservation practices (vegetated ditches, buffer strips or tailwater ponds) have minimal effect on runoff NO_3-N concentration.

Limiting the NO_3-N concentration of tile drain effluent to 10 PPM is even more problematic. NO_3-N concentration in the soil solution typically runs 3-5 times higher than soil NO_3-N expressed on a dry soil basis; this is because the solution phase weighs no more than 20-35% of dry soil, depending on texture. With vegetable crop root zones commonly containing 10-20 PPM NO_3-N on a dry soil basis, soil solution leaching from the root zone is typically several-fold higher. Surveys of tile drain effluent in the Salinas Valley have confirmed that NO_3-N concentration typically runs between 40-100 PPM.

While fertilizer management practices can reduce NO_3-N concentration somewhat, it is clear that some remediation technique for both surface water and tile drainage will be needed to meet regulatory standards. There are three plausible approaches to removing NO_3-N from surface runoff or tile drain effluent: reverse osmosis (RO), ion exchange (IE), and biological denitrification (BD). RO reduces the concentration of all ions, including NO_3-N, by filtration through a semi-permeable membrane. In IE NO_3-N is captured on an anionic resin, and a different ion (usually chloride) replaces it in solution. Both RO and IE are prohibitively expensive for agricultural applications; also, in both cases a brine is generated, the disposal of which is environmentally problematic.

BD has been widely recognized as a promising technology for agricultural runoff and tile drain effluent remediation (Schipper et al., 2010b). BD is a passive process in which bacteria reduce NO_3^- to gaseous N compounds (mostly N_2). The requirements for BD to occur are an anaerobic environment, the presence of facultative anaerobic bacteria capable of this transformation, and labile carbon to power bacterial growth and act as a terminal electron acceptor. BD occurs naturally in wetlands, but the rate of denitrification is often severely limited by carbon availability; given the high NO_3-N concentration and relatively high volume of tile drain effluent and surface runoff from vegetable farms, the use of constructed wetlands would likely be space-prohibitive. Additionally, constructed wetlands provide wildlife habitat, potentially creating microbial food safety issues.

The use of denitrification bioreactors has been widely studied (Blowes et al., 1994; Moorman et al., 2010; Robertson and Merkley, 2009; Schipper et al., 2010a, b; Warneke et al., 2011). One common approach has been to cycle drainage water through an impoundment filled with a carbon source, typically wood chips or other agricultural waste products. While most research to date has evaluated relatively small installations, Schipper et al. (2010a) has operated a 20 x 600 ft bioreactor in New Zealand since 2006, treating high NO_3-N nutrient solution discharged by a hydroponic greenhouse operation. They documented long-term denitrification rates up to about 10 g N per m^3 per day, roughly an order of magnitude above typical rates achieved in constructed wetlands. In addition to greater denitrification potential, bioreactors do not create wildlife habitat because there is no exposed water surface (the buoyancy of the organic media creates a floating layer).

The Project Leaders have recently constructed two bioreactors on tile-drained commercial farms in the Salinas Valley. The bioreactors are between 500 and 1,000 ft^3 in volume. Ground wood waste from the Monterey Regional Waste Management District was used as the carbon medium. This material, made primarily from untreated scrap construction wood, is available in sufficient quantity (approximately 7,500 tons per year) to represent a viable source of media for commercial-scale bioreactors in the Salinas Valley. At each of these sites tile drain effluent from a collection sump is circulated through the bioreactor. Monitoring of inlet and outlet water for NO_3-N, NO_2-N and, dissolved organic carbon has begun. These measurements will document the rate of denitrification, and describe the effluent water quality parameters of ecological significance to the receiving water bodies. Periodic measurement of nitrous oxide (N_2O) emission are planned.

The initial results have been positive. Reduction in NO_3-N concentration has ranged from 15-20 PPM per day of residence time in the bioreactor. However, this rate is likely to decline as the highly labile carbon is metabolized and the bioreactors reach a mature steady state. Initially high levels of dissolved organic carbon in the effluent has declined significantly after the initial weeks of operation, suggesting that the maturation process is relatively rapid.

Current grant support from a non-FREP source is sufficient to fund the management and monitoring of these bioreactors through the 2011 production season. However, understanding the long-term performance of DBRs is critical to evaluating the environmental and economic feasibility of the technology. This project proposes to continue the evaluation of these tile drain effluent bioreactors through 2013. Additionally, a new bioreactor will be installed and evaluated for the treatment of surface runoff from vegetable fields.

D. Objectives:

A. Evaluate the environmental and economic feasibility of denitrification bioreactors for the removal of nitrate from tile drain effluent and surface runoff from vegetable fields.

B. Extend the results of this research to coastal vegetable growers to stimulate action in compliance with water quality regulation.

E. Methods:

Treatment of tile drain effluent

The existing tailwater bioreactors will be managed and monitored through the 2012 and 2013 production seasons. Both sites are equipped with autosampling capability; at least 3 times per week flow-weighted influent and effluent samples from the previous 24 hours will be collected. NO_3-N and NO_2-N concentration will be determined on all samples. Dissolved organic carbon (which should be less variable) will be measured weekly. Water temperature in the bioreactors will be continuously logged. The pattern of dissolved oxygen level by position and depth in each bioreactor will be determined; this information will show how much of the bioreactor volume is sufficiently anaerobic to support denitrification, and may suggest construction or management changes to improve performance.

Flow rate into the bioreactors will be manipulated to vary hydraulic residence time so that scenarios of both complete and incomplete denitrification can be monitored. The rate of emission of the greenhouse gas nitrous oxide (N_2O) increases when denitrification is incomplete (Schipper et al., 2010b), and appears to be correlated with NO_2-N concentration (Warneke et al., 2011). Gaseous N_2O emission from the bioreactors and dissolved N_2O in effluent water will be measured by the methods of Warneke et al. The goal will be to relate easily measured parameters (NO_3-N or NO_2-N) in effluent to N_2O loss, to provide the operator a practical tool for bioreactor management to minimize greenhouse gas emissions.

Prior research suggests that mature wood chip bioreactors are carbon limited (Schipper et al. 2010b), and that the addition of a soluble carbon source may significantly increase the denitrification rate. To test this hypothesis we will evaluate the effect of injection of molasses or other relatively inexpensive soluble carbon source on the denitrification rate. Adding a soluble carbon source to enhance denitrification is a common practice in municipal wasterwater treatment, but to our knowledge this idea has not been applied to agricultural wasterwater treatment. If successful, this practice could reduce the size requirement for a bioreactor, and provide a tool for bioreactor management.

Treatment of surface runoff

An additional bioreactor of approximately 1,000 ft^3 volume will be constructed on a Salinas Valley farm during the 2012 production season to evaluate the treatment of surface runoff from vegetable fields. A two-stage system will be used. Runoff water will be treated with polyacrylamide (PAM) and pumped into a settling pond to reduce the sediment load; this water will then be cycled through the bioreactor. Water quality monitoring of influent and effluent from the bioreactor will be performed as previously described for the tile drain effluent bioreactors. Hydraulic residence time will be adjusted to reflect the lower NO_3-N concentrations typical of runoff compared to tile drain effluent.

One possible complication in the treatment of surface runoff is the potential for soluble pesticide residues to disrupt the biological activity in the reactor. Once the reactor has stabilized and the typical range of denitrification rates have been documented, the cause of any episode of substantially lowered denitrification rates will be investigated, with particular attention paid to the potential role of pesticide residue.

Based on the average denitrification rates achieved, an algorithm will be developed to estimate the bioreactor size requirement based on varying volumes of wastewater to be treated, and the mean NO_3-N concentration. The economic feasibility of employing biological denitrification on a commercial scale will be evaluated. Elements of this analysis will include equipment cost for bioreactor installation, material inputs, labor, interest on operating capital, management time requirement, and lost profit potential on any land taken out of production.

Workplan year 1:

Task 1. Construct denitrification bioreactor to treat surface runoff; operational by 1 June, 2012.
Task 2. Operate and monitor all three bioreactors.
Task 3. Initiate economic analysis.
Task 4. Submit interpretive summary and annual report to FREP.

Workplan year 2:

Task 1. Operate and monitor all three bioreactors
Task 2. Complete economic analysis.
Task 3. Conduct outreach program of field days and educational meetings, and develop web-based resources.
Task 4. Submit interpretive summary and final report to FREP, as well as a summary powerpoint presentation.

F. Project management, evaluation and outreach:

The project leaders will share the responsibility of identifying a field site and constructing the bioreactor to treat surface runoff. Day to day sampling and maintenance of the three bioreactors will be supervised by M. Cahn and R. Smith. Water and gas sample analysis and bioreactor management modifications will be the responsibility of T. Hartz. Economic analysis will be undertaken by L. Tourte.

During the 2013 production season two field day events will be held, one to showcase the use of bioreactors for the treatment of tile drain effluent, and one to demonstrate the treatment of surface runoff. Presentations on both the technique and economics will be made at the 2013 and 2014 annual Salinas Valley Irrigation and Fertilization meeting hosted by the Project Leaders. A web-based presentation on the construction and operation of a bioreactor will be developed and made accessible on the Monterey and Santa Cruz UCCE websites. A summary powerpoint presentation will be prepared and submitted with the FREP final report. All outreach efforts will be completed by 31 March, 2014.

G. Deliverables

Deliverables	Due Date
Interim Report w/Invoice For services 1/1/12--6/30/12	7/31/2012
Annual Report w/Invoice For services 7/1/12--12/31/12	1/31/2013
Interim Report w/Invoice For Services 1/1/13--6/30/13	7/31/2013
Final Report w/Invoice For services 7/1/13--12/31/13	1/31/2014

References:

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Warneke, S., L.A. Schipper, D.A. Bruesewitz, I. McDonald and S. Cameron. 2011. Rates, controls and potential adverse effects of nitrate removal in a denitrification bed. Ecol. Engineering 37:511-522.