6

Recycling Vertical-Flow Biofilter: A Treatment System for Agricultural Subsurface Tile Water

K.H. Baker[1] and S.E. Clark[2]
[1]*Life Science Program, Penn State Harrisburg*
[2]*Environmental Engineering Programs, Penn State Harrisburg*
USA

1. Introduction

Agricultural runoff and similar nonpoint sources of pollution are responsible for widespread degradation of surface water quality in the U.S. (Hall and Killen, 2005; Hardy and Koontz, 2008). In almost three-quarters of the rivers studied in the National Water Quality Survey, nonpoint discharges were major contributors to water quality impairment (US EPA, 1992). Nonpoint source discharges resulting from agricultural runoff add large amounts of inorganic nitrogen and phosphorus to surface water (Goolsby and Battaglin, 2001; Powers, 2007; US EPA, 1992). In the Chesapeake Bay Region (US), nonpoint source discharges contribute about two-thirds of the nitrogen and one-quarter of the phosphorus inputs (Correll *et al.*, 1995). In the 1200 km^2 Conestoga River watershed in Pennsylvania, 47.2 kg/ha/yr total nitrogen and 44.7 kg/ha/yr nitrate-nitrogen are discharged from nonpoint sources adding, ultimately, to the nutrient load of the Chesapeake Bay (Woltenmade, 2005). The addition of excessive inorganic nutrients to surface waters leads to eutrophication, which, in turn, is associated with the development of hypoxic zones such as those in the Gulf of Mexico, the Chesapeake Bay, and similar areas (Alexander *et al.*, 2008; Boesch *et al.*, 2001; Mitsch *et al.*, 1999; Wang *et al.*, 2001).

Subsurface tile drainage is a common agricultural water management practice used in regions with a seasonally high water table. By taking advantage of this system, farmers are able to extend their growing season by allowing for earlier spring planting and later harvest dates. The use of subsurface tile drainage has been shown to significantly improve crop production (Kladivko *et al.*, 2005). Skaggs *et al.* (1994) noted that subsurface artificial drainage has improved agricultural production on nearly one-fifth of U.S. soils. In the intensively cropped watersheds of the Midwest United States, the use of subsurface tile drainage has allowed one of the highest agricultural productivities in the world. Approximately 30% of all agricultural lands in the upper Midwest are artificially drained (Zucker and Brown, 1998).

Despite all of the benefits to crop production, tile drain lines can have a negative environmental impact. Tile drain lines can act as conduits for contaminants, promoting the rapid movement of these substances to surface waters (Fleming and Ford, 2004; Gentry *et al.*, 2000). A study of tile drain outlets in southwestern Ohio found an average concentration of nitrate-N of 17 mg L^{-1} was discharged to receiving waters (Fleming et al., 1998). The crop production system employed, the amount, rate, and timing of fertilizer application, the size and arrangement of drainage tiles, and the presence of cover crops are all known to influence nitrogen inputs to surface waters from tile drainage systems (Kaspar *et al.*, 2007; Kladivko *et al.*, 2004; Nangia *et al.*, 2008; deVos *et al.*, 2000; Domagalski *et al.*, 2008; Dinnes *et al.*, 2002).

Agronomic controls such as crop and fertilizer management, however, are not usually sufficient to rectify nutrient pollution resulting from tile drainage systems (Jaynes *et al.*, 2008; Madramootro *et al.*, 2007). Therefore, additional methods for nutrient removal and control are needed where subsurface tile drainage is common.

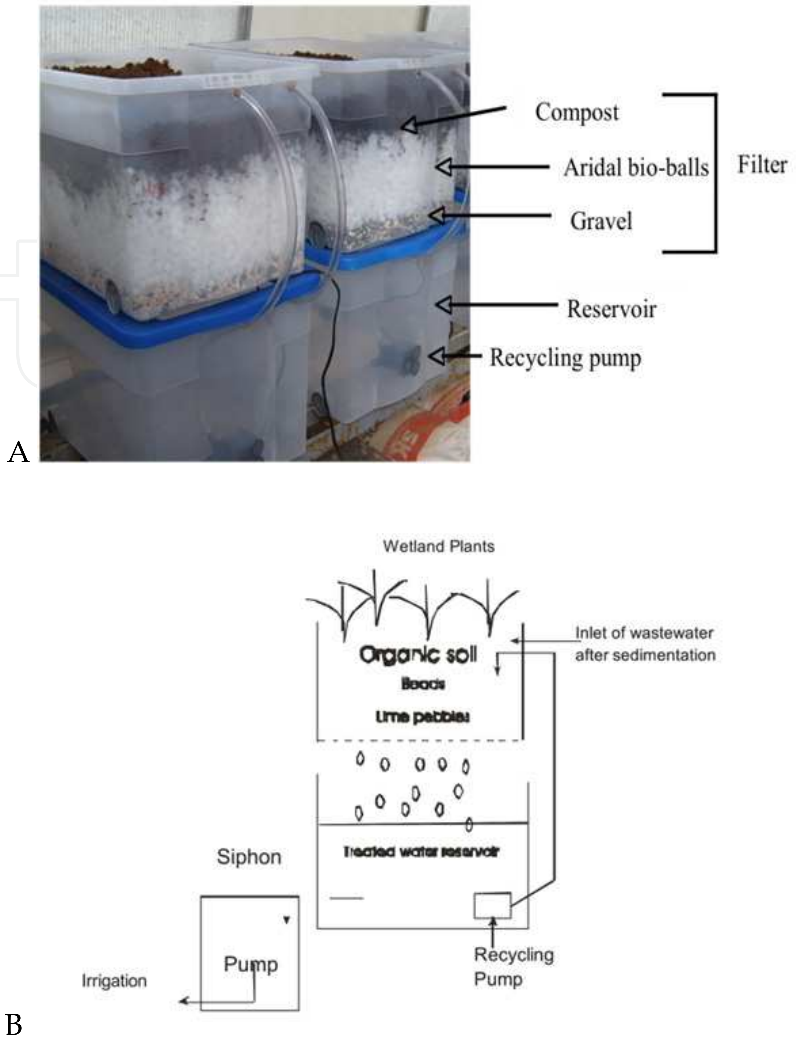
Passive treatment systems such as vegetated riparian zones and biofilters have been shown to be effective in controlling nutrient inputs from surface runoff (Cors and Tychon, 2007; Dodds and Oakes, 2006; Mankin *et al.*, 2007; Mayer *et al.*, 2007; Spruill, 2004; Yamada *et al.*, 2007). The preponderance of water flow in tile drainage systems though, is subsurface, within the vadose zone. Therefore, the efficiency of surface systems for treatment may be reduced because substantial amounts of contaminated water may bypass the active treatment zone. To address this limitation, subsurface systems such as *in-situ* bioreactors, permeable reactive barriers, biofilters, and subsurface flow constructed wetlands have been investigated (Bezbaruh and Zhang, 2003; Darbi *et al.*, 2003; Greenan *et al.*, 2006; Robertson *et al.*, 2007; Schipper and Vojvodic-Vakovic, 2000; Schipper and Vojvodic-Vakovic, 2001; Schipper *et al.*, 2004; Su and Puls, 2007; van Driel *et al.*, 2006). These subsurface systems generally depend on microbial denitrification to mineralize and remove nitrate. Denitrification is an anaerobic process. As such, it requires anaerobic conditions in the subsurface as well as an adequate supply of electron donors and available carbon. Thus, an exogenous source of carbon such as wood chips or sawdust is usually required for these systems to function properly (Greenan *et al.*, 2006; Lin *et al.*, 2002; Vymazal, 2007).

We recently reported on a recycling vertical-flow bioreactor (RVFB) for the treatment of household greywater (Gross *et al.*, 2007). This system intercepts and re-circulates contaminated water to a vegetated soil biofilter for aerobic treatment. We report here on the potential use of this system for the removal of excess nutrients from tile water.

2. Materials and methods

The mesocosm scale RVFBs used in this study have been described elsewhere (Gross *et al.*, 2007). Briefly, each unit consisted of two tiers, each made of a 55 x 40 x 30 cm plastic container. The top container functioned as a soil based treatment unit, while the bottom container served as a reservoir from which water was recycled continuously to the treatment unit (Figure 1).

The RVFB units were run with a total of 40 L of synthetic tile water (STW: [g L^{-1}] $CaCl_2$, 1.7; $NaSO_4$, 1.8; $NaHCO_3$, 0.1; KNO_3, 0.1; K_2HPO_4, 0.0004; Humic acid, 0.003) in a semi-batch mode. After initial loading of each unit, water from the reservoir was recirculated to the treatment unit at a rate of 0.41 L min^{-1} using a 4.6 L min^{-1} (5 watt) submersible pump. Milk tubing (0.635 cm) modified into a drip line provided uniform water distribution over the surface of the treatment unit. The recirculation rate was set to prevent ponding of water on the soil surface.



RVFB units used in this research. A. RVFB units at initial set-up of experiment. Note, no vegetation had been planted at this time. B. Schematic of RVFB.

Fig. 1. Recycling Vertical Flow Bioreactors (RVFB)

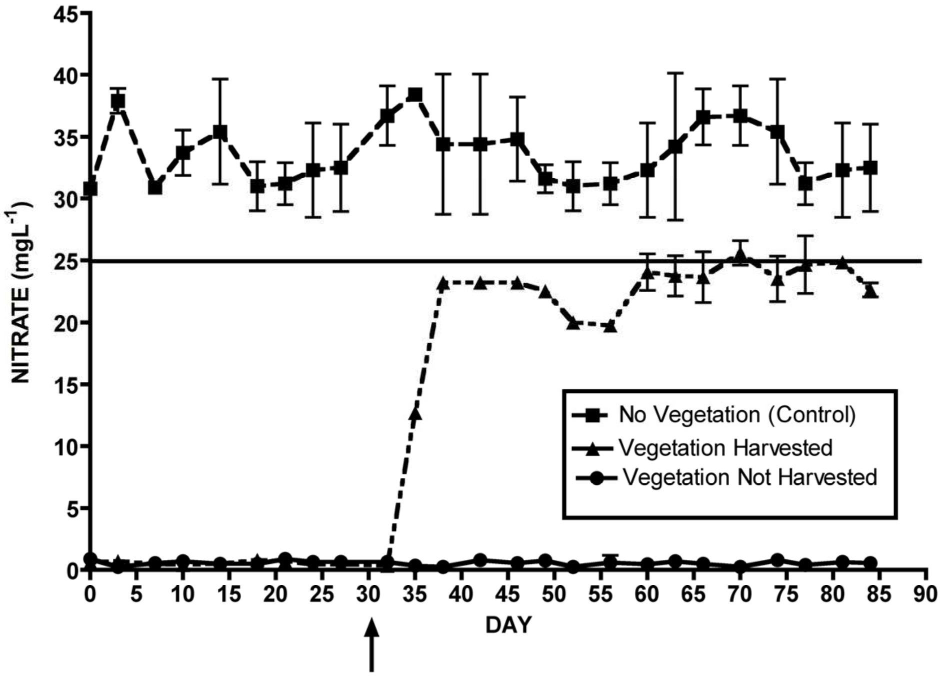
Evaluation of the RVFB was conducted under conditions typical of a temperate climate such as that found in the Mid-Atlantic region of the Eastern US. Experimental systems contained a mixed plant community of emergent plants common to southeastern Pennsylvania. An initial period of 4 weeks (designated weeks -4 to 0; data not shown) was allocated for the establishment of the plant community before STW was added for treatment. Plants were excluded from the control system by weeding twice per week. In addition, plants were harvested from one of the experimental treatments at day 30 of the growing season to assess the importance of vegetation in nutrient removal. The systems were maintained in a greenhouse at ambient temperatures for the duration of the study, one growing season (May – October).

After allowing for the initial plant establishment and system acclimation, samples were collected twice weekly by draining 20 L of effluent from the reservoir container of each RVFB and replacing it with 20 L of freshly prepared STW. An aliquot (1 L) of the drained effluent was transported on ice immediately to the laboratory for analysis. Samples were stored at 4^{o}C and analyzed within 24 hours of collection. Nitrate-nitrogen (NO_3-N), nitrite-

nitrogen (NO_2-N), and dissolved reactive (ortho) phosphate were assayed using standard chemical test kits (HACH Test-N-Tube Plus Methods 835/836, 839 and 834 respectively. All kits follow USEPA approved methods SM 4500. Hach Company, Loveland, CO.).
Data was analyzed using the statistical program Prism 4.0 (GraphPad, Inc). Treatments were compared using paired T-tests at a level of significance ($\alpha = 0.05$)

3. Results

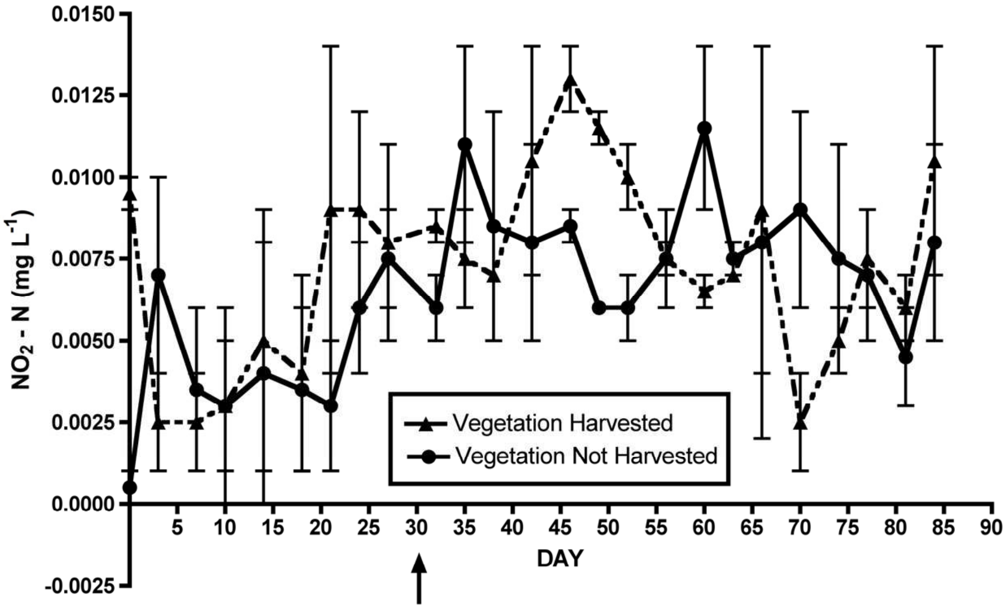
Figure 2 summarizes the removal of nitrate in the RVFB systems. There was no noticeable removal of NO_3-N from the influent tile water in the control system, indicating that passive removal via adsorption to the soil or microbial transformation was not a significant factor. Effluent nitrate concentrations in the vegetated systems were consistently below the EPA guidelines of 10 mg L^{-1}. In fact, effluent concentrations of NO_3-N in these systems rarely exceeded 2 mg L^{-1}, corresponding to a removal of > 90% of the influent NO_3-N. Harvesting of the plant community (day 30) resulted in a rapid increase in the effluent NO_3-N concentration. Within two weeks of the vegetation removal, the concentration of nitrate discharged by the harvested unit approached the concentration discharged in the control system indicating that the bulk of the nitrogen removal in the RVFB was the result of plant uptake and assimilation rather than of denitrification or other soil microbial processes. Nitrate levels in the effluent from the harvested unit remained significantly elevated, in excess of discharge limits, for the remainder of the study. The rapid increase in NO_3-N seen upon the removal of vegetation indicates that possible harvesting of the plants in a functioning RFVB should be limited to times when tile water discharge is minimal.



Mean +/- S.D. of effluent nitrate concentration in RVFB treating synthetic tile water (25 mgL^{-1} NO_3-N initial concentration: solid line). Plants were harvested in the 30th day of the experiment (arrow).

Fig. 2. Nitrate (NO_3-N) Removal in an RVFB

Ammonia-N in the effluent of all of the planted systems was consistently below 0.1 mg L^{-1} (data not shown). The concentration of NO_2-N was significantly ($p = 0.05$) lower in the vegetated units than in the control unit. (data not shown). Removal of vegetation from one of the vegetated units (Harvested; day 30) did not have a clear impact on the discharge of nitrite by that unit. While there appeared to be a slight elevation in the concentration of NO_2-N in the Harvested unit, this increase was transient and may not have been significantly different from the discharge of the remaining experimental units.



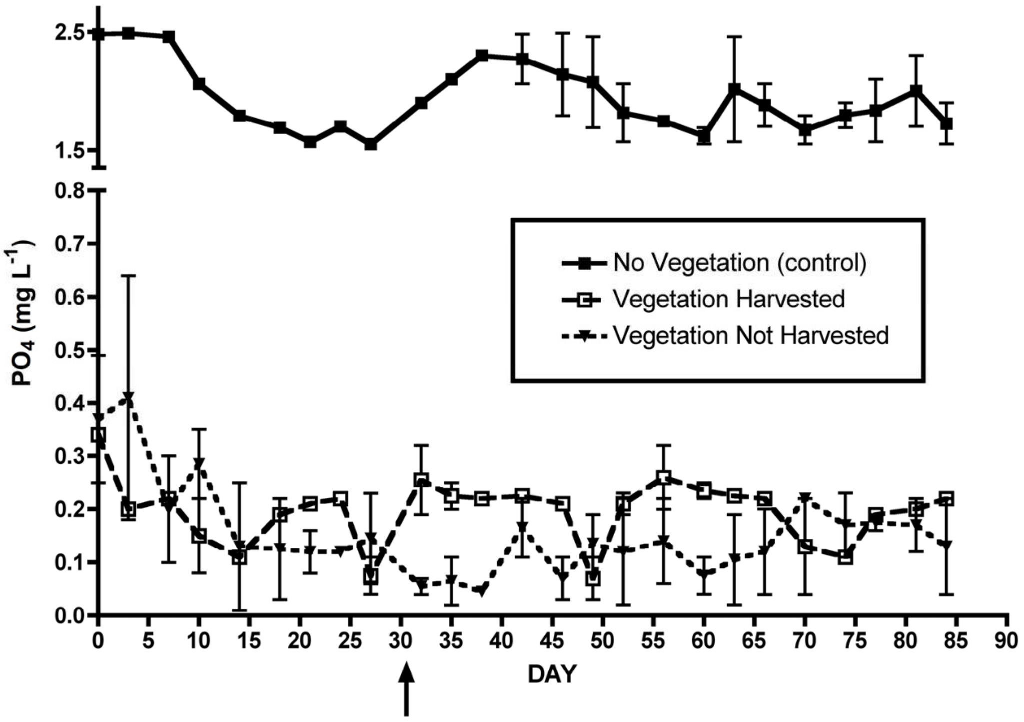
Mean +/- S.D. of effluent nitrite-N concentration in RVFB treating synthetic tile water. Plants were harvested in the 30th day of the experiment (arrow).

Fig. 3. Nitrite (NO_2-N) in RVFB Effluent

Removal of reactive phosphate from influent tile water was negligible in the RVFB without vegetation (Control; Figure 4). In fact, at times, the concentration of phosphate in the effluent was higher than that in the influent indicating that phosphate was being leached from the soil. In the presence of vegetation, the concentration of phosphate in the effluent was reduced to 20% of the control effluent. Removal of vegetation had no apparent impact on the concentration of PO_4 in the effluent. Retention of phosphate in the remaining root biomass as well as uptake by plant re-growth may account for the low concentrations of PO_4 in the post-harvest effluent, however, the specific cause of this pattern was not established.

4. Conclusions and future recommendations

Nutrient enrichment from non-point source runoff is a major factor in the degradation of surface water quality (Hardy and Koontz 2008, Ribaudo *et al.* 2001). The sources of nutrient runoff vary in scale from small individual households to large regional agricultural activities. Similarly, the options for prevention and remediation available for this type of pollution vary widely. Ultimately, multiple technologies at multiple scales must be available to address this issue (Ribaudo *et al.* 2001).



Mean +/- S.D. of effluent phosphate (PO_4) concentration in RVFB treating synthetic tile water. Plants were harvested in the 30th day of the experiment (arrow).

Fig. 4. Reactive (ortho) Phosphate in RVFB Effluent

The efficacy of management and control procedures in minimizing the runoff of nutrients has been documented widely (Mitsch *et al.,* 1999). However, agronomic practices alone are not enough to eliminate all agriculture-related nutrient runoff. In order to adequately reduce the impact of non-point source runoff, a combination of agronomic practices and treatment techniques is required.

A wide variety of treatment options for nutrient runoff have been developed. These include riparian buffer zones, biofilters, denitrification walls and constructed wetlands (Bezbaruah and Zhang, 2003; Darbi *et al.,* 2003; Jaynes *et al.,* 2008; Kelly *et al.,* 2007; Lin *et al.,* 2007; Su and Puls, 2007; Vymazal, 2007; Yamada *et al.,* 2007). Although each of these systems has been shown to reduce the NO_3-N concentration in groundwater, there is no single ideal system appropriate for use under all circumstances.

Our research demonstrates the potential use of a recycling vertical-flow biofilter (RVFB) as an alternative treatment option for the removal of nutrients from contaminated tile water. Using this relatively simple system we were able to achieve a > 95% removal of reactive phosphate and a > 90% removal of nitrate-nitrogen from STW.

The RVFB combines characteristics of a constructed wetland, a riparian buffer zone and a trickling filter for aeration. Subsurface flow intercepted by the RVFB is recycled to the soil surface. From there, it flows through a vegetated soil bed treatment system where combined biotic and abiotic processes remove excess nutrients and then flows through a layer of hollow plastic spheres, finally trickling into a reservoir. Movement of the water through the hollow spheres re-aerates the water and prevents the development of anaerobic conditions. Thus the RVFB is a hybrid treatment system combining the advantages of several existing treatment processes into one system capable of treating both surface and subsurface runoff.

For example, reactive phosphate is most likely removed by a combination of plant uptake and soil sorption. Removal of nitrogen compounds, on the other hand, is most likely the result of plant uptake as well as limited nitrification and denitrification by the soil microbial community.

The importance of plant uptake in the removal of nutrients is reflected in the increase in the concentration of both nitrate and phosphate in the harvested unit after the removal of vegetation from the system. No such increase in the concentration of nutrients was seen in units from which the vegetation was not removed. Because of the dominant role of vegetation in the RVFB, application of this technology to field situations must consider the management and ultimate use of the vegetation.

The RVFB has several advantages over other systems for the treatment of agricultural runoff. Since it is based on modular components – the upper soil treatment module, functionally similar to a riparian buffer, the plastic spheres, functionally similar to a trickling filter and the lower recirculation and reservoir module – there is flexibility in the design, allowing complete units to be tailored to a specific site. In addition, the use of separate modules should reduce maintenance costs since repair to a single component can be done by simply replacing the module without the need to disassemble the entire system and disrupting its operation.

In exploiting the ability of vegetated soil systems to sequester and transform inorganic nutrients, the RVFB reflects the advantages of a riparian buffer, a well-established treatment modality for the prevention of surface water pollution from agricultural runoff (Cors and Tychon, 2007; Mankin *et al.*, 2007; Mayer *et al.*, 2007; Schoonover *et al.*, 2005; Yamada *et al.*, 2007). By adding a subsurface recirculating reservoir, the RVFB also is capable of intercepting and treating subsurface runoff, particularly tile water that normally bypasses riparian buffers. Unlike constructed riparian wetlands, however, the RVFB operates in a primarily aerobic mode: water trickling through the soil and into the reservoir is aerated. Thus, the generation and release of nitrogenous greenhouse and ozone depleting gases and precursors of acidic deposition (e.g. N_2O) associated with denitrification-based systems may be avoided (Magner *et al.*, 2004; David *et al.*, 2009)

Our results provide a proof-of-concept only for the RVFB. Additional research is needed to demonstrate how well the system functions under realistic field conditions as well as the costs of this system compared to alternatives. We believe, however, that the RVFB has the potential to be a useful addition to the armamentarium in the fight against non-point source pollution.

5. Abbreviation list

RVFB: recycling vertical-flow bioreactor
STW: synthetic tile water

6. References

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environ. Sci. Technol. 42:822 - 830.

Bezbaruah, A.N., and T.C. Zhang. 2003. Performance of a constructed wetland with a sulfur/limestone denitrification section for wastewater nitrate removal. Environ. Sci. Technol. 37:1690 - 1697.

Boesch, D.F., R.B. Brinsfield, and R.E. Magnien, 2001. Chesapeake Bay eutrophication: scientific understanding, ecosystem restoration, and challenges for agriculture. J. Environ. Qual. 30:303 - 20.

Correll D.L., T.E. Jordan, and D.E. Weller. 1995. The Chesapeake Bay watershed: effects of land use and geology on dissolved nitrogen concentrations. Pages 639-648 in P. Hill and S. Nelson, eds. Towards a sustainable coastal watershed: The Chesapeake experiment. Chesapeake Research Consortium, Solomons, MD.

Cors M. and B. Tychon. 2007. Grassed buffer strips as nitrate diffuse pollution remediation tools: management impact on the denitrification enzyme activity. Wat. Sci, Technol. 55:25 - 30.

Darbi A., T. Viraraghavan, R. Butler, and D. Corkal. 2003. Pilot-scale evaluation of select nitrate removal technologies. J. Env. Hlth. Sci. A. Tox. Hazard Subst. Environ. Eng 38:1703 - 1715.

David, M.B., S.J. DelGrosso, X. Hu, E.P. Marshall, G.F. McIsaac, W.J. Parton, C. Tonitto, and M.A. Youssef. 2009. Modeling denitrification in a tile-rained, corn and soybean agroecosystem of Illinois, USA. Biogeochem. 93:7-30.

deVos J.A., D. Hesterberg, P.A.C. Raats. 2000. Nitrate leaching in a tile-drained silt loam soil. Soil Sci. Soc. Am. J. 64:517 - 527.

Dinnes, D.L., D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, and C.A. Cambardella. 2002. Nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. Agronomy J. 94:153 - 171.

Dodds, W.K. and R.M. Oakes. 2006. Controls of nutrients across a prairie stream watershed: land use and riparian cover effects. Env. Manag. 37:634 - 646.

Domagalski, J.L., S. Ator, R. Coupe, K. McCarthy, D. Lampe, M. Sandstrom, and N. Baker. 2008. Comparative study of transport processes of nitrogen, phosphorus, and herbicides to streams in five agricultural basins. USA. J. Environ. Qual. 37:1158 - 1169.

Fleming, R. and R. Ford. 2004. Suitability of "end-of-pipe" systems to treat farm tile drainage water. Ridgetown College-University of Guelph. http://www.ridgetownc.on.ca/Research/research_fleming3.cfm. Last accessed 06/19/08.

Fleming, R., M. MacAlpine, and C. Tiffin. 1998. Nitrate levels in soil, tile drainage water and shallow groundwater under a variety of farm management systems. CSAE Paper 98 - 101, Vancouver, B.C.

Gentry, L.E., M.B. David, and K.M. Smith-Starks. 2000. Nitrogen fertilizer and herbicide transport from tile drained fields. J. Environ. Qual. 29:232 - 240.

Goolsby, D.A. and W.A. Battaglin. 2001. Long-term changes in concentration and flux of nitrogen in the Mississippi River Basin, USA. Hydrol. Proc. 15:1209 - 1226.

Greenan, C.M., T.B. Moorman, T.C. Kaspar, T.B. Parkin, and D.B. Jaynes. 2006. Comparing carbon substrates for denitrification of subsurface drainage water. J. Environ. Qual. 35:824 - 829.

Gross, A., D. Kaplan, and K. Baker. 2007. Removal of chemical and microbiological contaminants from domestic greywater using a recycled vertical flow bioreactor (RVFB). Ecol. Eng. 31:107 - 114.

Hall, L.W. Jr. and W.D. Killen. 2005. Temporal and spatial assessment of water quality, physical habitat, and benthic communities in an impaired agricultural stream in

California’s San Joaquin Valley. J. Env. Sci. Hlth. A Tox. Hazard. Sub. Environ. Eng. 40:959 - 989.

Hardy, S.D. and T.M. Koontz. 2008. Reducing nonpoint source pollution through collaboration: policies and programs across the US states. Environ. Manag. 41:301 - 310.

Jaynes, D.B., T.C. Kaspar, T.B. Moorman, and T.B. Parkin. 2008. In situ bioreactors and deep-drain pipe installation to reduce nitrate losses in artificially drained fields. J. Environ. Qual. 37:429 - 436.

Kaspar, T.C., D.B. Jaynes, T.B. Parker, and T.B. Moorman. 2007. Rye crop cover and garnagrass strip effects on NO_3 concentration. J. Environ. Qual. 36: 1503 – 1511.

Kelly, J.M., J.L. Kovar, R. Sokolowsky, and T. Moorman. 2007. Phosphorus uptake during four years by different vegetation cover types in a riparian buffer. Nutr. Cycl. Agroecosyst. 78:239 -251.

Kladivko, E.J., J.R. Frakenberger, D.B. Jaynes, D.W. Meek, B.J. Jenkinson, and N.R. Fausey. 2004. Nitrate leaching to subsurface drains as affected by drain spacing and changes in crop production system. J. Environ. Qual. 33(5):1803-1813.

Kladivko, E.J., G.L. Willoughby, and J.B. Santini. 2005. Corn growth and yield response to subsurface drain spacing on Clermont Silt Loan Soil. Agron. J. 97:1419 - 1428.

Lin, Y.F., S.R. Jing, T.W. Wang, and D.Y. Lee. 2002. Effects of macrophytes and external carbon sources on nitrate removal in constructed wetlands. Environ. Pollut. 119:413 - 420.

Lin, Y.F., S.R. Jing, D.Y. Lee, Y.F. Chang, and K.C. Shih. 2007. Nitrate removal and denitrification affected by soil characteristics in nitrate treatment wetlands. J. Environ. Sci. Hlth. A. Tox Hazard Subst. Environ. Eng. 42:471 - 479.

Madramootoo, C.A., W.R. Johnston, J.E. Ayars, R.O. Evans, and N.R. Fausey. 2007. Agricultural drainage management, quality and disposal issues in North America. Irrig. and Drain. 56:535 - 545.

Magner, J.A., G.A. Payne, and L.J. Steffen. 2004. Drainage effects on stream nitrate-N and hydrology in South-central Minnesota (USA). Environ. Monitor. Assess. 91:183-198.

Mankin K.R., D.M. Ngandu, C.J. Barden, S.L. Hutchinson, and W.A. Geyer. 2007. Grass-Shrub riparian buffer removal of sediments, phosphorus, and nitrogen from simulated runoff. J. Am. Wat. Res Assoc. 43:1108 - 1116.

Mayer, P.M., S.K. Reynolds jr., M.D. McCutchen, and T.J .Canfield. 2007. Meta-analysis of nitrogen removal in riparian buffers. J. Environ. Qual. 36:1172 - 1180.

Mitsch, W.J., J.W. Day Jr., J.W. Gilliam, P.M. Groffman, D.L. Hey, G. Randall, and N. Wang. 1999. Reducing Nutrient Loads, Especially Nitrate-Nitrogen, to Surface Water, Groundwater, and the Gulf of Mexico. Topic 5 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, MD 111 p.

Nangia, V., P.H. Gowda, D.J. Mulla, and G.R. Sands. 2008. Water quality modeling of fertilizer management impacts on nitrate losses in tile drains at the field scale. J. Environ. Qual. 37:296 -307.

Powers, S.E. 2007. Nutrient loads to surface water from row crop production. Int. J. Life Cycle Assess. 12:399 – 407.

Ribaudo, M.O., R. Heimlich, R. Claassen, and M. Peters. 2001. Least-cost management of nonpoint source pollution: source reduction versus interception strategies for controlling nitrogen loss in the Mississippi Basin. Ecol. Econ. 37:183 - 197.

Robertson, W.D., L.J. Ptacek, and S.J. Brown. 2007. Geochemical and hydrological impacts of a wood particle barrier treating nitrate and perchlorate in ground water. Ground Wat. Monit. Remed. 27:85 - 95.

Schipper, L.A., and M. Vojvodic-Vukovic. 2000. Nitrate removal from groundwater and denitrification rates in a porous treatment wall amended with sawdust. Ecol. Eng. 14:269 - 278.

Schipper, L.A., and M. Vojvodic-Vukovic. 2001. Five years of nitrate removal, denitrification, and carbon dynamics in a denitrification wall. Wat. Res. 35:3473 - 3477.

Schipper, L.A., G.F. Barkle, J.C. Hadfield, M. Vojvolic-Vukovic, and C.P. Burgess. 2004. Hydraulic constraints on the performance of a groundwater denitrification wall for nitrate removal from shallow groundwater. J. Contam. Hydrol. 69:263 - 279.

Schoonover, J.E., K.W.J. Willard, J.J. Zaczek, J.C. Mangun and A.D. Carver. 2005. Nutrient attenuation in agricultural surface runoff by riparian buffer zones in Southern Illinois, USA. Agroforestry Systems 64:169-180.

Skaggs, R.W., M.A. Brevé, and J.W. Gilliam. 1994. Hydrologic and water quality impacts of agricultural drainage. Crit. Rev. Environ. Sci. Technol. 24:1 - 32.

Spruill, T.B. 2004. Effectiveness of riparian buffers in controlling ground-water discharge of nitrate to streams in selected hydrogeological settings of the North Carolina Coastal Plain. Wat. Sci. Technol. 49:63 - 70.

Su, C.M. and R.W. Puls. 2007. Removal of added nitrate in the single, binary, and ternary systems of cotton burr compost, zerovalent iron, and sediment: Implications for groundwater nitrate remediation using permeable reactive barriers. Chemosphere 67:1653 - 1662.

US EPA 1992. The national water quality inventory. The 1992 report to Congress. US EPA, Washington, DC.

Van Driel, P.W., W.D. Robertson, and L.C. Markley. 2006. Upflow reactors for riparian zone denitrification. J. Environ. Qual. 35:412 - 420.

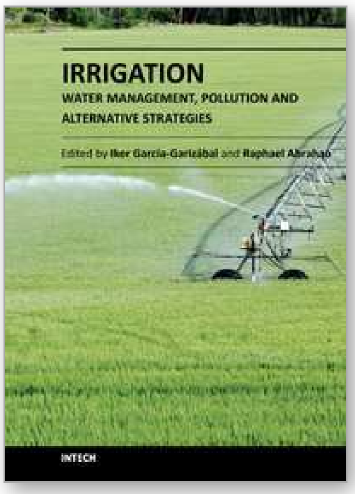
Vymazal, J. 2007. Removal of nutrients in various types of constructed wetlands. Sci. Total Environ. 380:48 - 65.

Wang, P, R. Batiuk, L. Linker, and G. Shenk. 2001. Assessment of best management practices for improvement of dissolved oxygen in Chesapeake Bay estuary. Wat. Sci. Technol. 44:173 -80.

Woltemade, C. 2005. Potential for treatment wetlands to reduce non-point source nitrogen loads on a watershed scale: Modeling the Conestoga River watershed, Pennsylvania, USA. Geophys. Res. Abst. 7.00344.

Yamada, T., S.D. Logsdon, M.D. Tomer, and M.R. Burkart. 2007. Groundwater nitrate following installation of a vegetated riparian buffer. Sci. Tot. Environ. 375:297 - 309.

Zucker, L. and L. Brown (eds) Ag Drainage: Water Quality Impacts and Subsurface Drainage Studies in the Midwest, Ohio State University Extension Bulletin #871.



Irrigation - Water Management, Pollution and Alternative Strategies
Edited by Dr Iker Garcia-Garizabal

ISBN 978-953-51-0421-6
Hard cover, 234 pages
Publisher InTech

Irrigated agriculture is the most significant user of fresh water in the world and, due to the large area occupied, is one of the major pollution sources for the water resources. This book comprises 12 chapters that cover different issues and problematics of irrigated agriculture: from water use in different irrigated systems to pollution generated by irrigated agriculture. Moreover, the book also includes chapters that deal with new possibilities of improving irrigation techniques through the reuse of drainage water and wastewater, helping to reduce freshwater extractions. A wide range of issues is herein presented, related to the evaluation of irrigated agriculture impacts and management practices to reduce these impacts on the environment.

K.H. Baker and S.E. Clark (2012). Recycling Vertical-Flow Biofilter: A Treatment System for Agricultural Subsurface Tile Water, Irrigation - Water Management, Pollution and Alternative Strategies, Dr Iker Garcia-Garizabal (Ed.), ISBN: 978-953-51-0421-6, InTech, Available from: http://www.intechopen.com/books/irrigation-water-management-pollution-and-alternative-strategies/recycling-vertical-flow-biofilter-a-treatment-system-for-agricultural-subsurface-tile-water

INTECH
open science | open minds

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821