Remediation of Runoff: Options for Container Plant Nurseries ¹

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In 2002, the state of Florida ranked 2nd in the U.S. for total number of ornamental nursery acres outdoors with approximately 14,973 hectares (37,000 acres) in the open [United States Department of Agriculture-National Agricultural Statistics Service (USDA-NASS), 2002]. As one of the largest agricultural industries in the state, plant nurseries constitute a large component of the economy of Florida with a total value of \$15 billion in 2006 (FNGLA, personal communication). Production of marketable plants involves much fertilization and irrigation even in a high rainfall region like Florida. Leachate or runoff containing nutrients, especially nitrogen (N) and phosphorus (P), and pesticide residues from agricultural operations including plant nurseries, are considered a non-point source of pollution. Environmental impacts of this pollution include eutrophication of natural waters, which eventually leads to ecological and economic costs. Container plant nurseries are assumed to contribute to contamination of water, but the magnitude of nursery contributions is not well known. Nitrogen and P concentrations in runoff are strongly influenced by nursery irrigation and fertilization management practices resulting in widely varying concentrations,

both spatially and temporally, within and around a given nursery. Concentrations of phosphate (PO₄) in samples collected from nursery drainage areas ranged from 0.60 mg L⁻¹ (0.60 ppm) during the winter to as high as 144 mg L⁻¹ (144 ppm) during the growing season (Sharma and Bolques, 2007). Nitrate-N (NO₃-N) concentrations were at times as low as 0.20 mg L⁻¹ (0.20 ppm) but up to 300 mg L⁻¹ (300 ppm) at some locations (Sharma and Bolques, 2007). Fertigation tended to increase the concentrations of nitrate-N and phosphate in the runoff immediately after it was applied. Wilson et al. (2006) reported nitrate-N concentrations ranging from 70-253 mg L⁻¹ (70-253 ppm) in irrigation/fertigation runoff water at bedding and foliage plant nurseries. While the runoff at some plant nurseries is captured and recycled for irrigation, at other operations it is not (Figures 1A, 1B, and 1C).

Excess N and P inputs can lead to eutrophication of natural waterbodies, resulting in accelerated plant and animal productivity in these systems (Nixon, 1998). While the drinking water level for NO₃-N is set at 10 mg L⁻¹ (10 ppm), total N of above 0.5 mg

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Fig. 1A. Runoff from production areas at an ornamental plant nursery.

Fig. 1B. A collection basin at a container plant nursery.

Fig. 1C. Water from collection basins is recycled often for irrigation.

L^{-1} (0.5 ppm) is reported to accelerate eutrophication in some systems. United States Environmental Protection Agency (USEPA) recommends not exceeding $0.1 \text{ mg } L^{-1}$ (0.1 ppm) total P in surface waters (USEPA, 1986). The Florida Department of Environmental Protection is currently developing watershed-specific guidelines for N and P concentration thresholds. Updates to the nutrient criteria development process can be found at <http://www.dep.state.fl.us/water/wqssp/nutrients/>.

Control of pollution from identifiable sources (point-source pollution) is easier to address because the point of pollution is easily seen. Municipal waste-water treatment facilities use a variety of physical, chemical, and biological methods to remove nutrients, metals, solids, and biological wastes from contaminated water before it is discharged into the environment or made available for other uses (i.e. reclaimed water for irrigation, industrial uses, etc.). Treatment technologies resulting in high quality, pure water include carbon adsorption, distillation, and reverse osmosis. These treatments allow for the re-use of formerly polluted water for industrial and agricultural purposes.

Removal of pollutants from non-point sources is more difficult because a specific point of discharge is typically not visible. This type of non-point pollution is associated with agricultural runoff, mining activities, urban development and paved roads. While currently non-point sources are not regulated in the same manner as point sources, there are efforts to implement protective measures nationwide. Section 303(d) of the Clean Water Act (CWA) requires states to submit lists of surface waters that do not meet applicable water quality standards (impaired waters) after implementation of technology-based effluent limitations, and establish Total Maximum Daily Loads (TMDLs) for these waters on a prioritized schedule. These TMDLs establish the maximum amount of a pollutant that can be discharged into a given water body without exceeding the natural assimilative capacity of the receiving waterbody. These threshold limits will become the water quality standards for affected waterbodies in the state. For several watersheds in Florida, TMDLs for many pollutants have been finalized (see <http://www.epa.gov/region4/water/tmdl/florida/>).

Implementation of TMDLs refers to any combination of regulatory, non-regulatory, or incentive-based actions that attain the threshold limits of pollutant loading. Best Management Practices (BMPs), which are non-regulatory actions, are structural or non-structural methods for reducing the environmental impacts and maximizing production and management efficiency. Remediation BMPs may

be used for removal of nutrient contaminants from runoff before the water is discharged off-site.

Nursery Runoff Remediation

Environmental remediation is defined as the removal of pollution or contaminants from environmental media such as soil, groundwater, sediment, or surface water for the general protection of human health and the environment. For on-site remediation of runoff at plant nurseries, several options are available. The choice and adoption of a method depends upon the volume of water to be remediated, the nutrient loads in the runoff, and the land area (space) available for installing the needed structures. Described below are some methods to improve the quality of runoff before discharging it into natural areas. This document is meant to provide a general description of possible remediation options.

Plant-Based Systems

These systems include constructed wetlands, or plant beds, which are structures where natural biogeochemical processes are used for removing contaminants from water. A combination of physical, chemical, and biological processes in constructed wetlands results in transformation and removal of nutrients and other contaminants. Plant roots provide surfaces for microbe-mediated nutrient transformation and plant uptake, and the organic matter serves as carbon source for microbial activity, which results in break-down and/or assimilation of nutrients. Microorganisms also facilitate nitrification and subsequent denitrification, which results in removal of nitrate from the system and in release of nitrogen gas (N_2) into the atmosphere. Phosphorus, on the other hand, can be taken up by plants or assimilated by microbes, or, under appropriate conditions, it can bind to iron, aluminum, and calcium compounds in the sediments. Harvesting of the above-ground biomass at the end of the growing season can maximize the amount of P removed by plants and prevent the P from being translocated into rhizomes. Finally, settling of the particulate matter also occurs, which results in filtering of suspended solids from the water. Constructed wetlands can be installed as surface flow or sub-surface flow wetlands.

Some Caveats

Because plant-based systems rely on biological activity of plants and microbes, seasonal variation in pollutant removal efficiency can occur. Plant uptake and microbial transformations are maximized during the warmer growing season, assuming sufficient quantities of the substrate nutrients are present. Also, while plant roots and accumulated organic matter can sometimes lead to clogging of pipes, placement of mesh screens over the openings can prevent such problems.

Surface Flow Wetlands

Surface flow wetlands are basins (Figures 2A and 2B) in which water can reside to a depth of up to 1 m (about 3 feet) in a pit or basin sealed with liner or with naturally heavy clay. Wetland plants (emergent macrophytes, submerged plants, and floating plants) are planted and water is moved through the basin by active pumping into the system. The outflow is typically driven by gravity. The volume of water pumped into the basin and the density of vegetation within the system determine the hydraulic residence time (HRT = the length of time water remains in the wetland) of the water. Hydraulic residence time is important in allowing contact of water pollutants with microbes, sediments, and plant roots. While, in general, longer retention times (several days) promote more complete remediation of many pollutants, the needed retention time is influenced by the hydraulic loading rate and percentage of wetland occupied by vegetation. Harvesting of the plants soon after the growing season, although somewhat laborious, is recommended to remove the nutrients accumulated in the plant biomass.

Sub-Surface Flow Wetlands

A sub-surface flow wetland is a sealed basin approximately 0.5 m (1.6 ft) deep filled with a porous substrate of sand or gravel to support wetland macrophytes (Figure 3). Water moves horizontally through the pore spaces between the substrate and plant roots, and remains below the surface of the substrate. A combination of physical, chemical, and biological processes through an interaction between water, substrate, plant roots, and microorganisms

Fig. 2A&B. Diagram of a surface vertical-flow wetland (A). Water flows, driven by gravity, through an in-ground sealed pit planted with wetland macrophytes. A series of three images (B) show the inflow pipe (left), surface (center), and the outflow pipe delivering water to another treatment cell (right) of a wetland constructed at a container plant nursery. Wetland macrophytes were planted in the basin, the base of which was layered with bark chips to assist in planting and for providing a carbon source for microbial activity. The water surface is typically covered with *Lemna* and *Wolffia* spp. in this system. Illustration and Images: Jyotsna Sharma. Credits: Jyotsna Sharma

drives the remediation of nutrients. The hydraulic residence time, as in any other remediation system, influences the removal of nutrients from runoff water. A hydraulic residence time between 2 and 5 days led to more than 84% and more than 65% N and P removal, respectively, in subsurface horizontal-flow reed beds receiving nursery runoff over the 12-month plant establishment period (Headley et al., 2001).

Fig.3. Diagram of a sub-surface flow wetland.

Non-Plant-Based Systems

Bacterial-Based Bioreactors

A bacterial-based nitrate-remediation bioreactor system is currently under development at the University of Florida/IFAS (Figure 4). This flow-through system utilizes consortia of denitrifying microorganisms captured on-site at a given nursery.

These microbes are ubiquitous in aquatic environments, and are typically attached to any type of solid substrate found under natural conditions. However, natural environmental conditions may not always be appropriate for denitrifying microbial populations to dominate. This experimental system provides the appropriate conditions (described below) for the denitrifying microbes to dominate and flourish.

Nitrate removal in this system is based on the nitrogen transformation process called denitrification (Eq. 1). This reductive process converts nitrate-nitrogen to nitrite-nitrogen, followed by nitric oxide, nitrous oxide, and finally di-nitrogen gas. This is a microbe-mediated process that occurs under anaerobic conditions and when an appropriate source of carbon is present. The carbon must be in an available form for the chemical reactions to occur. Additionally, at least three (3) carbon atoms must be present for every two (2) nitrate-N atoms converted to N_2 gas (Eq. 2).

For this remediation system to be effective, several issues must be addressed, including: what nitrate loadings and concentrations are expected from production areas, and what are the typical runoff flow rates and volumes that must be accommodated within the system. These considerations are especially important because they will determine the amount of surface area needed to be colonized by the denitrifying microorganisms, which in turn will influence the residence time needed to remove the nitrate. The type of substrate used for attachment of the microorganisms can vary significantly, as long as the hydraulic conductivity is sufficient for the flow rates needed. Ideally, the carbon and nitrate sources need to be present at least daily to ensure healthy microbial communities. If carbon or nitrate becomes limited, the microorganisms may become starved, thus lowering the nitrate removal activity of the system.

While preliminary research indicates nitrate removal rates greater than 90% are achievable in a flow-through system (residence time under 30 minutes), there are concerns about the potential impact of pesticides used in routine plant production on the microbial consortia. Despite these uncertainties, this system appears to offer a very promising option for space-limited nurseries.

Fig.4. Experimental, small-scale flow-through bioreactors installed at an ornamental nursery.

Denitrification Walls

A method for reducing nutrient contaminants from shallow ground water is through the use of denitrification walls (Figure 5). These are constructed by digging a trench perpendicular to groundwater flow. A carbon source, such as sawdust, is mixed with the natural substrate to form the wall. This 'wall' must be permeable to groundwater flow

for efficient functioning (Schipper et al., 2004, 2005).

Denitrification walls can reduce nitrate inputs to receiving waters by enhancing denitrification. The organic materials reduce the oxygen concentration of the ground water by stimulating aerobic respiration, and also provide a carbon source to denitrifying bacteria. The removal of oxygen is necessary because the denitrifying bacteria use oxygen as a terminal electron acceptor in preference to nitrate.

Documented nitrate removal rates by denitrification walls range from 0.014 to 30 g N m⁻³ of wall per day (0.00002-0.05 lb N yd⁻³ of wall per day) (Schipper et al., 2005). It is not possible to derive one rate for all situations in which denitrification walls are used, but the functionality of denitrification walls in field tests demonstrates their practical value. Design, carbon substrate, concentrations of nutrients encountered, and operating conditions can vary greatly, making design modifications necessary. There is also potential that water can short-circuit underneath denitrification walls if fine carbon sources are added to coarse, sandy substrates; this can limit nitrogen removal from the water. Adding coarse carbon sources can help alleviate this problem.

Fig.5. Diagram of a denitrification wall and its placement in the landscape.

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