

Using Landscape Plants for Phytoremediation

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INTRODUCTION

The Clean Water Act (CWA) is the cornerstone of surface water quality protection in the United States. Passed in 1972, and amended in 1997, this statute employs a variety of tools to, in part, manage polluted runoff. While initially focused primarily on “point source” (direct pollutant discharge) facilities (municipal sewage plants, industrial facilities), starting in the late 1980’s efforts increased to address “non-point” runoff sources such as streets, parking areas, construction sites, farms, landscapes, and other “wet-weather” sources (EPA 2008).

The pollutant loading found in urban runoff can have detrimental effects on water quality and water body ecosystems (Hsieh and Davis 2005). Pollutants are a major concern in stormwater runoff since these parameters are harder to control as a nonpoint source pollutant. Pollutant effects can include oxygen depletion, eutrophication, species stress and toxicity (Hsieh et al 2007). The impact of nutrients, mainly phosphorus and nitrogen, on water quality is of particular concern, because nutrients in runoff can cause eutrophication where algal blooms grow excessively and deplete dissolved oxygen levels and increase turbidity. This can then result in poor water quality and low biodiversity. Nutrients in runoff can be contributed by fertilizers, atmospheric deposition, soil erosion, animal wastes and detergents. Phosphorus can exist as both dissolved and particulate forms in runoff and include organic and inorganic components (Hsieh et al 2007). Nitrogen can exist as both organic forms and inorganic forms such as ammonia, nitrate and nitrite.

Heavy metals such as copper, lead, zinc, and cadmium are carried in stormwater runoff and can bioaccumulate in aquatic systems because they cannot be broken down into less toxic forms. Sources of heavy metals are present almost everywhere and include car brake pads, building siding and roofs, tires, and atmospheric deposition. As these heavy metals bioaccumulate, the levels can become too toxic for aquatic life to tolerate and may lead to death (Davis et al 2001).

Stormwater best management practices (BMPs) are used to lessen the impact of urban runoff on water quality, flooding, and erosion (Hsieh and Davis 2005). The use of plants to remediate contaminated soils and wastewater has been practiced internationally for some time, but new research is being conducted to determine how effective plants are at removing contamination from polluted waters due to both stormwater and wastewater discharges (Wang et al 2002). Phytoremediation is an emerging technology that uses plants to degrade, extract, contain, or immobilize contaminants such as metals, pesticides, explosives, oil, excess nutrients, and pathogens from soil and water (EPA 2000). Phytoremediation has been identified as a more cost effective, noninvasive, natural, and publicly acceptable method of removing environmental contaminants than most chemical and physical methods (Arthur et al. 2005).

Both nitrogen (N) and phosphorus (P) are macronutrients needed for agronomic and horticultural plant growth, and are components of all complete fertilizers. Fertilizer application to residential, commercial, and municipal lawns and landscapes is a major non-point source of pollution with potential for reduction via phytoremediation. Though run-off from farms is generally decreasing due to nutrient management, run-off control techniques, and an overall decline in farmland, run-off from urban and suburban areas continues to increase as more land is developed, more native filtering plants are removed, and more hardscaped areas are installed.

The heavy metals copper (Cu) and zinc (Zn) are micronutrients for plants, and accumulate in the plant tissue in higher concentrations than other metals such as cadmium and lead that accumulate in the plant roots since they are not as mobile. A variety of research studies have been conducted to determine what plant species, both aquatic and terrestrial, can best accumulate heavy metals without toxic effects to the plant, and are identified as metal hyperaccumulators. Metal uptake is dependent upon plant species and availability of dissolved metals in the water. Dissolved metals available for plant uptake can depend on the amount of organics in the system, retention time, pH, redox likelihood, and particle bound metals. Plants also affect dissolved metal availability due to their effect on soil pH and oxygenation (Fritioff and Greger 2003).

The majority of plants currently used in phytoremediation applications, including storm water ponds (BMPs), riparian buffers, rain gardens, green roofs, constructed wetlands, etc., are herbaceous or non-woody. New storm water runoff systems that incorporate woody landscape plants into the systems, such as the Filterra[®] Bioretention System (Americast 2009), are being designed for streetscapes and landscapes. If commonly used landscape trees could be used for storm water (and soil) phytoremediation our trees would have an added environmental value. It is therefore important to screen commonly available landscape trees for their potential use in these systems.

Phytoremediation research with woody trees and shrubs has been more limited, with the willows (*Salix* sp.) having been identified as significant hyperaccumulators. Pollutant bioavailability and uptake by plants is very much dependent upon the rhizosphere processes. A major part of the rhizosphere microbial community is mycorrhizal fungi which form a symbiotic relationship with plant roots. Because they help transfer nutrients and metals to plant roots these associations play an important role in mediating plant uptake. Microorganisms in the rhizosphere will biologically transform pollutants into less toxic forms through enzymatic detoxification, thus making them available for plant uptake via the mycorrhiza (Arthur et al 2005). Willows do form mycorrhizal associations, and preliminary research has indicated a potentially significant contribution of mycorrhizas to accumulator willow heavy metal uptake (Wenzel 2005). A study by Wenzel (2003) found that the willow species accumulated the most metals in their leaves, with concentrations highest just before leaf fall. Wenzel's study showed that willow, a fast growing species, is most suitable for phytoextraction of metal-contaminated soils. According to Arthur et al (2005), hyperaccumulator species are able to tolerate high metal concentrations in their biomass through the use of phytochelatin which are sulfur-rich proteins.

The objectives of our initial research were to: 1. Use a nutrient uptake screening protocol for landscape trees and shrubs that was originally designed using water hyacinths as the remediation plant. This will determine what plants currently in nursery production have phytoremediation

capabilities, or what plants not common in the industry need to be produced for phytoremediation use; 2. Screen landscape plants in situ and in Filterra[®] Bioretention Systems stormwater management units to compare nutrient and heavy metal accumulation from landscape soil vs. the Filterra[®] system substrate. For both objectives both native and non-native landscape plants were used to determine which might be hyperaccumulators with phytoremediation potential.

MATERIALS AND METHODS

Modified Hydroponic Screening

In 2007 and 2008, using a protocol developed for phytoremediation screening with water hyacinths (Fox et al 2008), several species of woody shrubs, including redbud or redbosier dogwood (*Cornus sericea*), buttonbush (*Cephalanthus occidentalis*), and deciduous holly or winterberry (*Ilex verticillata*) were subjected to increasing levels of N and P (Figure 1). Whole plants were harvested and dried, and leaves were weighed and subjected to N and P analysis using the method described for the water hyacinths.



Figure 1 – The modified hydroponic system used to evaluate woody shrub accumulation of N and P. (In the foreground are the water hyacinths used to develop the protocol.)

Landscape Screening

In 2007 and 2008, to begin to compare the accumulation of N, P, Cu, and Zn accumulation, woody shrubs were planted in landscape sites adjacent to Filterra[®] units. A unique feature of the Filterra[®] unit is that it holds a substrate into which a shrub or tree is planted. These units have been field evaluated for their removal efficiency of N and P, along with suspended solids and some heavy metals (Figure 2). Several sites in Norfolk, VA and the Richmond, VA area were selected for evaluation. For statistical purposes, a requirement of each site was a minimum of three same sized Filterra[®] units planted with the same shrub. That shrub was then planted into landscape soil a few feet from the Filterra[®] unit. The major species used for this evaluation were several hollies (*Ilex* sp.), crape myrtle and redbud dogwood. Each fall, mature leaves evenly distributed around the shrubs were harvested, dried, and weighed, and then subjected to N, P, Cu, and Zn analysis again using the method described for the water hyacinths (Figure 3).



Figure 2 (left) – Hollies planted in Filterra[®] units installed in a parking lot with replicate landscape holly in background. Figure 3 (right) – Collection of leaves from a holly for N and P analysis.

RESULTS AND DISCUSSION

Modified Hydroponic Screening

There was a definite trend for all species used in the modified hydroponic system to grow larger and accumulate more N and P in their tissue as the rate of N and P in the water increased, with no signs of excessive nutrients (no marginal necrosis, etc.). These evaluations will be repeated in 2009, possibly using higher levels of N and P. Several species of willow were started in a nursery at HRAREC in 2006 to evaluate both their phytoremediation potential and their landscape suitability (size, growth rate, color, etc.)

Landscape Screening

One of the most important components of the Filterra[®] Bioretention System is the plant since it plays a critical role in pollutant uptake. Release of nutrients from substrate absorption sites makes this a sustainable system. Though a range of N, P, and heavy metal percents is available generically for deciduous and evergreen trees and shrubs, there are few ranges known for individual species and/or cultivars. The leaves of the shrubs planted in the landscape soil were used as a baseline nutrient content against which the shrubs in the Filterra[®] units could be compared. With a few exceptions and regardless of shrub species, there was more N, P, Cu, and Zn in the leaves of the plants in the Filterra[®] units than in the landscape plants. This suggests that these shrubs may be able to “luxury feed” or act as hyperaccumulators.

DISCUSSION

Identifying trees and shrubs that can be used for phytoremediation would increase the perceived and real value of landscape plants, and would be an additional marketing tool available to nurseries. Incorporation of these plants into streetscapes and landscapes, or nursery buffers, could improve water quality and the image of the green industry that is seen as a contributor to water pollution. Many of these plants might be appropriate to use not only in specific stormwater treatment systems such as Filterra[®], but also in bioretention cells, riparian buffers, constructed wetlands and other landscape-based stormwater treatment features to increase the use of plants for phytoremediation. These hyperaccumulators could be available nationwide from nurseries

and could thus be used by the green industry, governments, private businesses, non-profits, and communities.

It is hoped that once results are disseminated, nurseries will begin to produce effective plants, and members of the landscape design and installation industries will begin to specify and install said plants. Future extensions of this study will evaluate additional tree and shrub species in future Filterra® installations. Several other commercial landscape species (and their cultivars), including the shrubs abelia (*Abelia x grandiflora*), inkberry (*Ilex glabra*), anise (*Illicium floridanum*), cherrylaurel (*Prunus laurocerasus*), Scarlet Curly willow (*Salix x 'Scarlet Curly'*), and vitex (*Vitex agnus-castus*), and the trees Amur maple (*Acer ginnala*), Little Gem magnolia (*Magnolia grandiflora* 'Little Gem'), and corkscrew willow (*Salix matsudana* 'Tortuosa'), have a size, configuration, and environmental tolerance that should make them good plants for Filterra® systems. Evaluation would follow the same protocol of testing them in both Filterra® systems and adjacent landscape sites at new installations. In selecting plants for hydroponic screening and landscape planting, choosing plants with fibrous root systems would allow for more adsorption sites for pollutant uptake.

Future investigations may look at protocols to include harvesting roots and shoots since different metals accumulate in different parts of the plant based on a study by Fritioff and Greger (2003). Plant heavy metal and nutrient concentrations may vary based on collection area due to different runoff concentrations, and may be due to uptake ability and uptake sites among the plants. Fritioff and Greger's study could not identify pH or organic matter content in sediments having an effect on metal uptake. The study did demonstrate that metals are available for plant uptake at a pH near 6.0.

High accumulation of metals in terrestrial and emergent plant roots could stabilize the soil and prevent leaching of heavy metals according to Fritioff and Greger. Terrestrial plants show good uptake of cadmium and zinc in the root system. Certain plant species have storage organs in their rhizomes that also store heavy metals, and thus have potential to be used as phytoremediators, especially in a percolation system for stormwater treatment.

Our preliminary research is encouraging that the identification of specific plants for bioaccumulation of pollutants seems possible. Future research is still needed for advancing phytoremediation as a technology. This includes studying how to screen and harvest plants, choosing an assortment of plants for particular pollutants of concern, understanding mechanisms for nutrient and heavy metal removal, and ideal environments for maximum plant uptake.

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BIOGRAPHY

Ms. Mindy Ruby is the Research & Development Manager of the Filterra Stormwater Treatment Products Division. She is responsible for the technical development and investigation of products for stormwater treatment, as well as producing technical reports and assisting with submissions for approvals. Ms. Ruby received her Bachelor of Science degree in Environmental Studies from Randolph-Macon College with a minor in Biology, and is currently working on her Masters Degree in Horticulture from Virginia Tech.

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