Rain gardens: understanding their benefits and their beauty©

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INTRODUCTION

Rain garden systems are one of the most commonly utilized stormwater control measures (SCMs) to capture and remove pollutants [such as nitrogen (N), phosphorus (P), zinc (Zn), copper (Cu), cadmium (Cd), lead (Pb), and total suspended solids (TSS)] from stormwater runoff (Davis et al., 2001, 2009; Hunt et al., 2012). They are constructed by excavating the existing soil within the landscape and refilled with 0.7-1 m of a sand/soil/organic matter engineered filter bed substrate (Davis et al., 2009). They are then planted with vegetation (Liu et al., 2014; NCDENR, 2009). Rain gardens can be placed in many different landscape scenarios. They function well for containing and remediating polluted stormwater runoff because of their two main components: (1) the engineered filter bed substrate (EFBS) and (2) the vegetation.

An EFBS has to have an appropriate infiltration rate (speed that water enters the EFBS) and saturated hydraulic conductivity (speed that water moves through the saturated EFBS) so that water can be conveyed through the system appropriately. Both infiltration and saturated hydraulic conductivity can be impacted by the surrounding (native) soil, which will impact exfiltration out of the rain garden, as well as by the different substrate components utilized and will change with time. Sand-based EFBSs [85-88% (by volume) sand, 8-12% (by volume) fines (silt and clay), and 3-5% (by volume) organic matter] are commonly recommended due to their suitable hydraulic conductivity and permeability (Hsieh and Davis, 2005; NCDENR, 2009). However, slate-based (MS-16 100% expanded slate, Permatill, Carolina Stalite Company, Salisbury, North Carolina) EFBSs have been shown to convey water well and may be a better choice for small rain gardens with high inflow volumes due to their higher infiltration and saturated hydraulic conductivity rates (Turk et al., 2014). Paus et al. (2014) found that the saturated hydraulic conductivity of rain gardens with either a sandy loam or a sand EFBS tended to increase with time near the surface of the system, possibly due to vegetation maturation, bulk density reduction, and freeze thaw cycles.

Engineered filter bed substrates also need to have binding potential for pollutant remediation. Hunt et al. (2008) reported that a rain garden with a loamy sand EFBS capturing runoff from an asphalt parking lot had effluent concentrations of total N, total Kjeldahl N, and NH_4-N that were 32.2, 44.3, and 72.3% lower than that of the influent concentrations. Also, total P in the effluent was reported to be 31.4% lower than that of the influent (Hunt et al., 2008). Turk et al. (2014) reported that a slate-based EFBS had better remediation of N (86% initially and 99% by the end of the 18 month study) than the sand-based EFBS. These researchers also reported that slate and sand had good P removal, 99% and 96% respectively (Turk et al., 2014). Aged pine bark (PB) is often used as the organic matter source in EFBSs; however, compost utilization as an organic matter source may provide many benefits, such as plant growth enhancement from nutrients, pollutant binding, and microbial support.

Arrangement of EFBS components within a rain garden system can also improve runoff retention and remediation. Layering of varying EFBS components can cause a saturated anaerobic zone within the rain garden system as shown by Hsieh et al. (2007b). An anaerobic zone within a rain garden system can promote the loss of N by the process of denitrification (Tiedje et al., 1984). A permeable sand layer over a less permeable soil layer increased stormwater retention within the EFBS and allowed nitrification in the well-

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aerated sand portion of the substrate and denitrification in the saturated, low permeable soil layer (Hsieh et al., 2007b). The less permeable bottom soil layer also increased contact time between dissolved P and the EFBS resulting in more effective total P removal (Hsieh et al., 2007a). Palmer et al. (2013) reported that utilizing a saturation zone within the rain garden system greatly reduced NO_3^- in effluent (71% compared to 33% without a saturated zone) when the EFBSs consisted of a 60% sand, 15% compost, 15% finely shredded cedar bark, and 10% aluminum-based drinking water treatment residuals mix. While the same was not true for $O\text{-}PO_4$, which was remediated better without a saturation zone (80%) compared to with a saturation zone (67%) (Palmer et al., 2013). However, the anaerobic zone needs to be located near the bottom of the rain garden system to prevent detrimental effects on plants such as root stress from anoxia or favorable environment created for root pathogens (Tiedje et al., 1984).

Vegetation in rain gardens can also have a positive impact on remediation and has been reported to improve the remediation of N and P from simulated polluted stormwater when compared to non-vegetated rain gardens (Read et al., 2008; Bratieres et al., 2008). Turk et al. (2014) reported that 176 days after planting plant uptake appeared to have a greater impact on remediation than EFBS composition. Gautam and Greenway (2014) grew a variety of Australian species in gravel, loam, and sand EFBSs. These researchers found that plants with the faster growth rates and larger biomass production retained greater amounts of nutrients in their roots and above ground structures (Gautam and Greenway, 2014). Plant parts accounted for 2.7-4.3% of the total P and 8.7-17.7% of the total N retained in the rain garden system (Gautam and Greenway, 2014).

Care should be taken when selecting plants to insure survival and functionality within the rain garden. Plants growing in rain gardens face two challenges: low nutrient levels in the influent (compared to typical fertility programs) and periodic drought conditions. The average total N ranged from 1.13 to 2.19 mg L^{-1} and average total P ranged from 0.07 to 0.33 mg L^{-1} for stormwater runoff from eight asphalt parking lots in North Carolina (Passeport and Hunt, 2009). These N and P concentrations are much lower than the N (50 to 100 mg L^{-1}) and P (10 to 15 mg L^{-1}) rates recommended for application during containerized nursery production (Bilderback et al., 2013). As rain gardens are non-irrigated landscape features, plants (within a rain garden system) need to be able to tolerate extended periods between rainfall while maintaining aesthetic appearance and maintaining transpiration. Several species have been evaluated and have proven to grow well and be aesthetically pleasing (Table 1). Vegetation in rain gardens also must be able to return water back to the hydrologic cycle through evapotranspiration (ET). Evapotranspiration is the process where water in the soil-plant system is transferred to the atmosphere and it includes both evaporation from the surface of the soil and transpiration from plant canopies (Hillel, 2004). The process of ET is critical in meeting long-term hydrology goals with rain gardens (Hunt et al., 2012). Low ET rates impact the water within and the water table below the rain garden system (Hunt et al., 2006). Increased ET from rain garden systems, may be achieved by utilizing types of vegetation that have long root systems increasing opportunity for storage by the media and for vegetation to take up water in between events (Hunt et al., 2012).

CONCLUSIONS

The EFBS, in combination with the appropriate vegetation make rain gardens functional and efficient at remediating pollutants and controlling volumes from polluted stormwater runoff. There are many different pollutants of concern and many different ways that rain gardens can be incorporated into the landscape. Plantings within rain gardens can be arranged so that they can divert and slow surface flow for filtration of sediments (Davis et al., 2009). Also, the plantings within a rain garden can be arranged so that they are aesthetically pleasing and support wildlife. Within the environment of a rain garden plant roots can aid in supporting the microbiological populations that may aid in degradation of pollutants and they should help in media permeability (Davis et al., 2009). Also, in order to most efficiently remediate pollutants and control the volume of polluted stormwater runoff, the size of impervious surface and the pollutants of concern, as well as the EFBS composition, need to be thought of beforehand (Hunt et al., 2012; Riley et al., 2013; Turk et al., 2014).

Table 1. List of species that have been evaluated in rain gardens and have worked successfully.

Scientific name	Common name	Reference
Betula nigra	River birch	Turk et al., 2014
Betula nigra 'Duraheat'	River birch	Turk et al., 2014
Eutrochium maculatum 'Gateway' (syn. *Eupatorium purpureum* subsp. *maculatum* 'Gateway')	Joe-pye weed	Turk et al., 2014
Helianthus angustifolius	Swamp sunflower	Turk et al., 2014
Helianthus angustifolius 'First Light'	Swamp sunflower	Turk et al., 2014
Itea virginica	Virginia sweetspire	Turk et al., 2014
Itea virginica 'Henry's Garnet'	Virginia sweetspire	Turk et al., 2014
Juncus effusus	Common rush	Turk et al., 2014
Monarda fistulosa	Beebalm	Riley et al., 2013
Magnolia virginiana	Sweetbay magnolia	Turk et al., 2014
Magnolia virginiana 'Sweet Thing'	Sweetbay magnolia	Turk et al., 2014
Panicum virgatum	Switchgrass	Turk et al., 2014
Panicum virgatum 'Shenandoah'	Switchgrass	Turk et al., 2014; Riley et al., 2013

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