A Case for Native Soil Landscaping BMP's

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The goal of the permitted bioretention system in St. Louis is to move towards pre-development hydrology by holding back the first 1.14 inches of rainfall and allowing that rainfall to infiltrate into the soil. St. Louis bioretention design includes replacement of native soils with an engineered soil that is a 65-85% sand mix, accompanied by an underdrain where drainage is poor. The purpose of the engineered soil is to increase infiltration of the rainwater into the bioretention system. The purpose of the underdrain is to prevent excessively long ponding by allowing delayed release of filtered rainwater through the underdrain.

In the residential setting, under voluntary conditions, where the installation is led by the homeowner, and where there is otherwise no construction occurring onsite, there are reasons why native soil may be preferable to the use of an engineered sandy soil mix. Furthermore, in certain situations, other native soil BMP's employed in addition to or instead of a rain garden may be an appropriate approach.

The engineered bioretention system relies primarily on changing soil texture to increase water infiltration into the soil. In contrast, the native soil landscaping approach relies primarily on improving soil structure to increase the infiltration of water into the soil. There is significant scientific evidence to support the latter approach.

Impact of soil texture on infiltration rates

Part of the reasoning behind replacing native soil with engineered soil is that soil texture influences infiltration rates; a sandy loam soil typically has a higher infiltration rate than silt loam which has a higher infiltration rate than clay loam soil; the larger particle size of sand creates more pore space between particles than for silt or clay. Soil texture is not the only factor influencing infiltration rates, however. Case in point is a North Central Florida study testing the infiltration rates of sandy soil. This study found a wide variability in infiltration rates in sandy soils across both compacted and non-compacted sites. In addition, for locations affected either by construction activity or by compaction treatments, sandy soil infiltration rates were typically reduced by 70-99% (Gregory, *et. al,* 2006). Conversely, USGS has published a study including a prairie-vegetated rain garden in urban clay loam soil with applied compost. This native soil rain garden enjoyed a median infiltration rate that increased from .28 in/hour to .88 inches/hour over a five year period. The improved infiltration rate was sufficient to retain and infiltrate 100% of all precipitation and snowmelt events from the years 2004-2007. Although a clay loam rain garden planted with turf-grass instead of prairie plants did not experience a similarly improved infiltration rate, it was nonetheless able to capture 96% of rainfall over the same period (Selbig, 2010). The clay loam rain gardens were sized with a ratio of approximately 5:1 contributing area to receiving area and to a depth of 6 inches. (Annual rainfall is 37 inches in Madison Wisconsin, vs 43 inches in St. Louis, Missouri). The Wisconsin study erases a common misperception that water will not infiltrate into high clay soils. Not only can water infiltrate into a clay loam soil, but native soil rain gardens can effectively be designed to capture 95% or more of rainfall events, even under clay loam conditions. Furthermore, as observed in the Florida study, sandy soil under disturbed conditions can have poor to non-existent infiltration rates; low infiltration rates do not automatically translate to high-clay soil conditions. Soil texture alone does not provide a complete picture for understanding soil infiltration rates.

Impact of soil structure on infiltration rates

Soil structure is a key soil attribute influencing infiltration of water into the soil. According to a NRCS definition (http://www.mt.nrcs.usda.gov/about/lessons/Lessons_Soil/structuredef.html), "Soil structure is the way in which the individual particles—sand, silt, and clay—are arranged into larger distinct aggregates" This aggregation of soil particles has been demonstrated to improve water infiltration rates. According to one soil study, "surface soil structural stability, surface residue accumulation, and surface-SOC [Soil Organic Carbon] … are critical features that control water infiltration and subsequent water transmission and storage in soil" (Franzluebbers, AJ, 2002). Soil organic matter improves infiltration rates because it "sustains many key soil functions by providing the energy, substrates, and biological diversity to support biological activity, which affects soil aggregation and water infiltration. Aggregation is important in: (i) facilitating water infiltration; (ii) providing adequate habitat space for soil organisms; (iii) adequate oxygen supply to roots and soil organisms; and (iv) preventing soil erosion. " Franzluebbers goes on to state that "the stratification ratio of SOC [Soil Organic Carbon] could be used as a simple diagnostic tool to identify land management strategies that improve soil water properties (e.g., infiltration, water-holding capacity, and plant-available water)".

Because of the complex interactions of soil organic carbon, micro-fauna, macro-fauna , plant roots and the impact of those interactions on soil quality and infiltration rates, as well as the impact that disturbing the soil has on decreasing infiltration rates, leaving the existing native soil in place is sometimes recommended as a Best Management Practice. One example is Chapter 4 of the nationally recognized *Sustainable Sites Initiative: Guidelines and Performance Benchmarks 2009*, which calls on the landscape architect to "minimize soil disturbance in design and construction". The initiative also points to model soil BMP requirements to improve water quality as promoted in the *Washington State DOE Stormwater Manual.* Washington's soil BMP(www.BuildingSoil.org) emphasizes the importance of improving water quality by building healthy soil as summarized in five steps:

1. Retain and protect native topsoil and vegetation where practical.
2. Restore disturbed soils, to restore healthy soil functions, by:
    - Stockpiling & reusing good quality site soil, or
    - Tilling 2-3" of compost into poor site soils, or
    - Bringing in 8" of compost-amended topsoil
3. Loosen compacted subsoil, if needed, by ripping to 12" depth
4. Mulch landscape beds after planting
5. Protect restored soils from erosion or re-compaction by heavy equipment

The *WDOE Stormwater Management Manual for Western Washington* requires preserving site topsoil and vegetation where possible, reducing soil compaction, and amending disturbed soils with compost to restore healthy soil functions. These are a few examples where a focus on restoring the original ecosystem function of native soil rather than altering soil texture with an engineered soil mix are employed as a means to improve soil infiltration rates and therefore water quality.

The above mentioned studies and best management practices provide evidence of and precedence for the effectiveness of native soil rain gardens and other landscaping BMP's to improve water quality, even under urban or small particle size conditions. There are also additional reasons why native soil may be preferable to the use of an engineered sandy soil mix when applied in the residential setting in voluntary situations where the installation is led by the homeowner and where there is otherwise no construction occurring onsite.

Soil texture is not uniform

In addition to the fact that soil texture is a poor indicator of infiltration rates, particle size is also not uniformly distributed, either within soil layers on site, or across the region. The St. Louis County section of the online Missouri Cooperative Soil Survey describes the Winfield-Urban land complex, which dominates in the Deer Creek Watershed in St. Louis County, as follows:

> "Typically, the surface layer of the Winfield soils is dark brown silt loam about 5 inches thick. The subsurface layer is yellowish brown silt loam about 5 inches thick. The subsoil is about 50 inches thick. It is dark yellowish brown silty clay loam and is mottled in the lower part. The substratum is brown, mottled silt loam. In places, the upper part of the subsoil has gray mottles. Also in places, 10 inches or less has been removed from the surface or the surface has been covered by as much as 10 inches of fill material, generally from basement excavations."

Reference St. Louis topsoil is primarily a silt loam texture. In some cases, however, development practices have either removed the topsoil layer or covered it with excavated subsoil, leaving only a relatively impervious compacted subsoil on site. In other cases, where pre-1960's development practices have been employed, and the original topsoil does remain, studies indicate that the widespread use of mowed turf grass with 1" root systems may allow for the formation of a hardpan clay shelf a couple of feet beneath the topsoil (Selbig, 2010).

In the case where there is intact urban topsoil with a clay shelf beneath the turf grass, an infiltration test can be expected to show a .2 to 1 inch per hour infiltration rate (Selbig, 2010). The test, however, will not reveal the distance from the surface of a clay layer in the soil. Although physical removal of the clay shelf will improve infiltration rates, there is no way to tell the homeowner how deep to dig in order to remove the shelf. If the homeowner digs too deep, he or she not only incurs greater costs, but may risk making the bottom of the rain garden lower than the water table, which would negatively affect infiltration rates by allowing groundwater to seep into the system. On the other hand, if the homeowner does not dig down deep enough to physically remove the clay shelf when planting the system, the plants are likely to adapt to the inserted large particle size soil, in a phenomenon known as the "bathtub effect". These plants are then less likely to either break through the clay shelf underneath or into the surrounding soil, leading to a tendency of the roots to instead curl around, seeking more sandy soil mix and open pore space. The Madison study documents how deep-rooted prairie plants will naturally grow to remove the clay shelf over time (Selbig, 2010), thus increasing the infiltration rate of the system. The rain gardens in this study were also installed without under drains. Furthermore, initial observations of demonstration rain gardens installed with no under drains in University City, Missouri seem to indicate that those rain gardens are functioning well. Data is currently being collected to substantiate those observations.

In the case where development practices leave only an impervious subsoil onsite with an expected 0 to .2 inch/hour infiltration rate, as was experienced by the Deer Creek Watershed Alliance team in a Creve Coeur demonstration rain garden, such a rain garden would only be expected to function effectively if paired with an underdrain. Even under these conditions, the system would serve primarily as a water filter. The "sponge" effect, or volume reduction rate, will be significantly limited by the impervious soil surrounding the rain garden. Furthermore, experience shows that there are numerous factors working against the installation of an underdrain in a setting that is both residential and voluntary. Of 12 demonstration residential rain gardens installed in the Deer Creek Watershed, none have under drains. In 10 out of 12 cases, under drains were not recommended in the design because of technical obstacles in tight yard spaces, as well as concerns regarding the expected installation and maintenance costs that under drains add to the system. In all 12 demonstration rain gardens, a gravel berm was installed as an alternative to an underdrain. [A compost sock check dam or vegetated soil berm (Tyler, et.al, 2010) might be appropriate alternatives to the gravel berm, in order to temporarily hold back water in the rain garden as well as filtering the water as it passes through the berm.] In one case where an underdrain was recommended by the design team because the rain garden was surrounded by subsoil that had an effective infiltration rate of zero, the underdrain was nonetheless refused by the homeowner.

Where the infiltration rate of the soil is less than .25 inches/hour, the homeowner could certainly select the option of voluntarily installing a bioretention system with engineered soil paired with an underdrain. Another approach, however, in cases where the infiltration rate of the soil approaches zero, would be to add a 6- 8" layer of topsoil to the entire yard (except under existing trees or shrubs which might suffocate plant roots), as per Washington State soil BMP guidelines, as an alternative to building a rain garden. Thus the homeowner will contribute to restoring pre-development hydrology by restoring pre-development soil, i.e., a high quality silt-loam mix. The effectiveness of this approach would be further enhanced if amended soils are paired with the addition of deep/fibrous rooted plants to the landscape, such as a combination of trees, shrubs, and prairie/meadow vegetation. In a 2008 study, Virginia Tech scientists used a container experiment to establish that urban tree roots have the potential to penetrate compacted subsoils. In one study, roots of both black oak and red maple trees penetrated clay loam soil compacted to 1.6 g cm-3, increasing infiltration rates by an average of 153% (Bartens, 2008). In addition, trees are excellent stormwater pumps. The amount of stormwater runoff that a typical 45 inch diameter oak tree may intercept is in the neighborhood of 15,416 gallons per year (treebenefits.com). Furthermore, tree planting is estimated to be 3-6 times more effective in managing stormwater per $1,000 invested than conventional methods. (Alliance for Community Trees, 2011)

Small soil berms installed on the downhill sides of these plantings will further slow the rate of water runoff and increase water infiltration into the soil. Where residential yard soil has been so altered as to be effectively impervious, this combined native soil restoration/vegetation re-landscaping approach may be more effective than a traditional bioretention system in achieving volume reductions goals over the long term.

Installation & maintenance risks & costs

The reason that engineered soil needs to be at least 65% and perhaps even 75% sand or more is because incorporating sand at a lower percentage than that will have the opposite of the desired effect, decreasing rather than increasing the pore space between particles, as the smaller silt or clay particles settle in between the sand particles (Spomer, 1983 & Trowbridge et. al, 2004). Because this negative outcome is counter-intuitive, however, there is risk that the homeowner may improperly try to incorporate small amounts of sandy soil rain garden mix into the existing soil instead of removing and replacing the soil, thus inadvertently creating a soil mix resembling concrete. There is also greater risk of soil compaction from the machinery that needs to be brought in to remove existing soil, thus further potentially compromising soil infiltration rates.

If the engineered soil rain garden is not kept well mulched and is exposed to the surrounding yard, there is risk that erosion of silt or clay particles from the yard will settle in between the sand particles in the rain garden and cause clogging over time. The maintenance costs incurred in reversing the clogged system also adds to the overall cost. The native soil rain garden does not incur a similar risk because of a lack of broad variation in particle size. Instead, infiltration rates in the native soil rain garden would be expected to improve over time as soil structure improves.

Other risks include that fact that, when digging 2-4 feet into the soil, there is risk of damaging tree roots, which in turn can cause surrounding trees to weaken or die. Finally, engineered soil reduces the range of plant survivability. With an underdrain, the high infiltration rates of sandy soil will only support plants tolerant of extremely xeric, or dry conditions. When no underdrain is included, water will fill the large pore spaces and may drown plant roots that are not tolerant of extremely mesic, or wet conditions.

The cost of removing existing soil and replacing it with engineered soil is greater than amending existing soil with compost, calcine clay, and/or hadite. In the later case, labor costs are lower, much smaller quantities of imported amendments are needed, and transporting the removed soil offsite becomes unnecessary. The native soil rain garden with organic mulch and no other amendments is even more cost effective. Further study is needed to quantitatively assess the risk & cost/benefit ratio of an engineered soil vs a native soil approach to improving water quality in a voluntary, residential setting.

Soil amendments

Covering exposed soil with an organic hardwood mulch, planting (preferably native or nativar) plants with extensive root systems, adding micro-organisms such as mycorrhizae, a specialized fungi that enhances the functioning of roots, to native soil, and/or amending native soil with well-aged compost, calcine clay or hadite (expanded shale) are features that will work together in a native soil rain garden to improve soil and also naturally remove a hardpan clay shelf within a 5 year period, which will in turn increase water infiltration rates.

Some studies indicate that if compost is included in a sandy soil mix, increased phosphorus run-off and therefore a negative impact on water quality can result. If compost is added to a silty clay loam under the same circumstances, there is an increased concentration of phosphorus in the runoff, but the overall amount of phosphorous runoff is actually *lower*. The increased infiltration properties provided by the compost in the silty clay loam more than offset the amount of phosphorus in the remaining runoff. (Spargo, 2004 & 2006) Phosphorous binds to clay particles in the soil, where micro-organisms in the compost can convert it to an organic form available for plant uptake. Thus, phosphorus runoff concerns provide yet another basis for selecting native over engineered soil where appropriate.

Meramec River endangerment

According to Roy Gross of St. Louis Composting, Mississippi River or Missouri River sand is not appropriate for incorporating into engineered soil. The medium grain sharp sand from the Meramec River is the best local source. At the same time, a watershed management plan drafted by East West Gateway Council of Governments identifies gravel mining as a key threat to the water quality of the Meramec River. Widespread use of engineered soil in the St. Louis region can only be expected to increase that demand. Regional water quality implications, and not just on site water quality implications should be taken into account in deciding whether to take an engineered soil or native soil approach to improving water quality.

Impact of woodland restoration on stormwater management

Certain areas of St. Louis County, and in particular the Deer Creek Watershed, have remaining intact pockets of mini-woodlands. A woodland habitat, in its original, reference state, is a nearly perfect stormwater filter. For example, a 1961 study of a 2.3 acre forested sub-watershed found runoff to be less than .6% of precipitation, an effective stormwater retention rate of 99.6%. (Leopold, et. al. 1964) Surface runoff in forests is mitigated by a combination of canopy interception, litter interception, stemflow guiding rainwater directly to root systems, soil infiltration, and evapotranspiration rates (Chang, 2003).

Many suburban woodland tracts, however, have become heavily infested with bush honeysuckle, which affects all of the above processes. A survey of bush honeysuckle, or amur honeysuckle (*Lonicera maackii*), research reveals that leaf biomass is 1.5 times lower in honeysuckle infected woods, negatively affecting canopy interception of rainfall. (Trammell, et. al, 2011) Furthermore, honeysuckle leaf litter decays faster and causes sugar maple litter to decay faster, affecting both organic matter accumulation and nitrogen retention in the soil. (Trammell, et. al, 2011). Honeysuckle has a primarily shallow root system (Deering, 1999) which can be expected to negatively influence the water holding capacity of the soil. Most importantly, the presence of bush honeysuckle has an adverse affect on both tree seedling density and tree seedling diversity, and its early spring to late fall leafing also shades out all groundcover plants (Hutchinson, 1996). The prevention of tree seedling establishment results in an increasingly widely spaced tree canopy over time. The bare soil caused by rapid leaf litter decay as well as the prevention of both tree seedling and herb growth increases runoff and erosion rates. Over time, a honeysuckle infested woodland can be expected to edge out other plant life (Collier, 2002) and evolve from one of the "most … complicated vegetation communities on Earth" (Chang, 2003) to a primarily monoculture shrub terrain with higher runoff and lower infiltration rates than a reference forest.

Woodland restoration can be expected to improve water quality if 1) honeysuckle is removed, 2) honeysuckle is replaced with a diversity of native plants including trees documented to have a high water interception rates as well as appropriate climax understory and groundcover plants, 3) when on steep sloped terrain, measures are taken to prevent soil erosion while new plants are becoming established.

Summary

In conclusion, a rain garden can achieve the goal of capture of the first 1.14 inches of rain without an underdrain and without replacing existing soil with a sandy soil mix in residential settings where no development is taking place so long as initial infiltration rates are .25 inches per hour or greater, and prairie or other deep rooted plants are utilized in the rain garden.

Percent Soil Organic Matter in the soil is a better indicator of infiltration rates than soil particle size. A healthy soil ecosystem will result in aggregated soil particles, improved soil structure, and therefore improved infiltration rates.

Where infiltration rates are lower than .25 inches per hour, improving soil infiltration rates by adding appropriate soil amendments and deep rooted plants across a wide section of the yard is an excellent alternative to installing an engineered bioretention system with an underdrain. Trees and healthy woodland replacement are also excellent storm water pumps for managing and infiltrating runoff.

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