Soil amendments to enhance phosphorus sorption

Principal mechanisms for phosphorus (P) removal in bioretention are the filtration of particulate-bound P and chemical sorption of dissolved P (see Hunt et al., 2012). Most stormwater control measures (SCMs) capture particulate P by settling or filtration, but leave dissolved P (typically phosphates) untreated. This untreated P accounts on average for 45 percent of total phosphorus in stormwater runoff and can be up to 95 percent of the total phosphorus, depending on the storm event (Erickson et al., 2012). Dissolved phosphorus is bioavailable and represents a significant concern for surface water quality.

Phosphorus sorbing materials contain a metal cation (typically di or trivalent) that reacts with dissolved phosphorus to create an insoluble compound by adsorption or precipitation or both (Buda et al., 2012). Soil components and amendments that have been shown to be effective in increasing chemical sorption of dissolved P include

- iron filings (Erickson et al., 2012);
- steel wool (Erickson et al., 2007);
- native iron rich soils such as those in the Piedmont of the Mid and Southern Atlantic USA (Hunt et al 2012), or Krasnozem soil in Australia (Lucas and Greenway, 2011);
- Drinking Water Treatment Residuals (WTRs), which are a by-product of drinking water treatment and a source of aluminum and iron hydroxides (O'Neill and Davis, 2012a and 2012b, Hinman and Wulkan, 2012; Lucas and Greenway, 2011; Lucas and Greenway, 2010); and
- sorptive media (Imbrium) (Balch et al 2013)

Caution: Acceptable amendments include the following.

- 5 percent by volume elemental iron filings above IWS or elevated underdrain;
- minimum 5 percent by volume sorptive media above IWS or elevated underdrain;
- minimum 5 percent by weight water treatment residuals (WTR) to a depth of at least 10 centimeters; and
- other P sorptive amendments with supporting third party research results showing P reduction for at least 20 year lifespan, P credit commensurate with research results

Buda et al. (2012) provide a literature review of P-sorption amendments. Characteristics of ideal P-sorption amendments include low cost, high availability, low toxicity for soil and water resources, potential for reuse as a soil amendment once fully saturated, and no toxicity to plants, wildlife, or children. It is also crucial that soil amendments not negatively impact soil infiltration rate and the ability to grow vigorous plants. Some P sorptive amendments, such as water treatment residuals (WTRs), are waste products turned into a resource to reduce P in bioretention (or agricultural) soils. Results from much of the research to date on use of P-sorbing materials to reduce nutrients in stormwater effluent are promising, but much remains to be learned about lifespan and long term effects of P-sorbing materials on soils and plants.

Contents

Benefits

P sorptive amendments have been shown to provide effective P retention for the expected lifetime of bioretention facilities (e.g. Lucas and Greenway, 2011; O'Neill and Davis, 2012a and 2012b). The presence of healthy vegetation plays a crucial role in extending P reduction lifespan of amendments.

Types of P-sorbing materials

The primary P-sorbing chemicals are calcium (Ca), aluminum (Al) and iron (Fe). These are found in a variety of materials.

Limestone or calcareous sand

Combinations of C 33 sand with limestone or calcareous sand were tested in laboratory columns by Erickson et al. (2007). Limestone or calcareous sand showed strong retention of phosphorus but clogged the columns, resulting in hydraulic failure. On-going field studies are looking at the potential for calcium-based systems to remove phosphorus. Examples include studies by Ramsey-Washington Watershed District (http://www.rwmwd.org/) to determine effectiveness of spent lime (http://therippleeffectmn.blogspot.com/2016/05/whats-next-for-wakefield-lake.html) and a permeable limestone barrier (http://www.rwmwd.org/index.asp?SEC=4E60DBB3-6315-4110-930B-633CF260D92D&Type=B_BASIC), and a study by Riley-Purgatory-Bluff Creek Watershed District (http://www.rpbcwd.org/) to determine the effectiveness of a spent lime system (http://www.rpbcwd.org/news/work-has-begun-lake-susan-treatment-system/). Long-term monitoring of these systems will provide useful information for determining if calcium-based systems can provide effective treatment for dissolved phosphorus.

Drinking Water Treatment Residuals (WTRs)

Drinking-water treatment residuals are primarily sediment, metal (aluminum, iron or calcium) oxide/hydroxides, activated carbon, and lime removed from raw water during the water purification process (Agyin-Birikorang et al., 2009). WTRs are increasingly being used to control phosphorus in soils where phosphorus leaching may be problematic for water quality. Kawczyinski and Achtermann (1991) reported that landfilling is the predominant disposal method, followed by land application, sanitary sewer disposal, direct stream discharge, and lagooning. WTRs contain high concentrations of amorphous aluminum (Al) or iron (Fe), making them potential amendments for sorbing soil phosphorus.

Aluminum-based Water Treatment Residuals (WTRs)

O'Neill and Davis (2012a and 2012b) recommend a bioretention soil media of 5 percent WTR, 3 percent triple-shredded hardwood bark mulch, and 92 percent loamy sand for P reduction on the basis of batch, minicolumn, and large column studies. The life expectancy for this media was 20 years. In a comparison of bioretention soil medias (BSM's) with varying fines concentrations, they found that increasing the concentration of sand (i.e. decreasing fines) improved P reduction. They also found that hardwood bark mulch, a source of organic matter typically low in P, further improved P reduction (O'Neill and Davis 2012a). The authors contend that an oxalate-extractable aluminum-, iron-, and phosphorus-based metric, the oxalate ratio, can be used to predict P sorption capacity, and suggest that a media oxalate ratio of 20 to 40 is expected to meet P adsorption requirements for nutrient sensitive watersheds. This media adsorbed 88.5 percent of the applied P mass, compared to a non-WTR amended control media for which effluent P mass increased 71.2 increased.

O'Neill and Davis (2012b) state "This media consistently produced total phosphorus effluent mean event concentrations less than 25 micrograms per liter and exhibited a maximum effluent concentration of only 70 micrograms per liter". Concentrations of P as low as 25 micrograms P per liter may be necessary to reduce eutrophication risk depending on receiving water conditions (U.S. Environmental Protection Agency (US EPA, 1986) in O'Neill and Davis, 2012a). References to additional studies are found in O'Neill and Davis (2012a and 2012b).

Iron-based Water Treatment Residuals (WTRs)

As reviewed in O'Neill and Davis (2012 a), one study of iron based WTRs found iron based WTRs to be ineffective to P reduction because they solubilized and released all adsorbed P in reducing conditions, but another more recent study found this may not be the case. According to Dr. Allen Davis (University of Maryland), iron based water treatment residuals "should work just as well, maybe better than Al. The concern with Fe is that if the media becomes anaerobic due to flooding or any other reason, the Fe can be reduced and will dissolve. It adds another layer of complexity to the system." This concern can be addressed by designing the bioretention practice to ensure the layer where P sorbtion will occur stays aerobic.

Iron filings

Research by Erickson et al. (2012) suggests that the lifespan for iron enhanced sand filtration (5 percent iron) with a typical impervious area ratio should be at least 30 years. Dissolved phosphorus capture should be greater than 80 percent for more than 30 years (Erickson, 2010). Many agricultural studies have also found several forms of iron enhancements to be effective to capture P (e.g. Chardon et al., 2012; Stoner et al. 2012; literature review in Buda et al. 2012). Research showing that native iron-rich soils also have high P sorption capacity further supports giving dissolved P removal credit (e.g. Lucas and Greenway, 2011). Stenlund (2013 personal communication) has observed that adding iron to soil causes the soil to harden to a rock like medium, and recommends augering holes for plant growth into soils that have been amended with iron.

Imbrium Sorptive®MEDIA

Imbrium Sorptive®MEDIA, a proprietary P sorbing amendment available from Contech, is an engineered granular media containing aluminum oxide and iron oxide that demonstrates substantial capacity for adsorption of dissolved phosphorus from stormwater runoff. A recent study reported results from monitoring P reduction of 5 bioretention mesocosms with varying concentrations of Imbrium Sorptive®MEDIA (Balch et al 2013). The study is summarized below.

Five individual bioretention cells were monitored, each with 50 cm (20 inches) depth of soil that consisted of sand and 15 percent peat moss. The authors state “Four of [the cells] had different concentrations of Sorbtive® Media (3, 5, 10 and 17 percent by volume). The fifth cell contained only the sand/peat soil mix and no amendment, and therefore represented a control that provided the ability to determine how much phosphorus was retained by the sand/peat mix alone. The total volume of spiked artificial stormwater applied to each cell approximated the volume of cumulative runoff generated in this region [Canada] over a two-year period by a drainage area five times the size of a bioretention cell. At every phosphorus concentration, all the cells amended with Sorbtive® Media demonstrated much higher percent removal of phosphorus compared to the control cell with no Sorbtive® Media. The performance gap between the amended cells and the control cell widened as the phosphorus concentration increased. At the 0.2 percent target phosphorus concentration, mean dissolved phosphorus removal ranged 79 to 92 percent for the amended cells compared to 54 percent for the control cell. At the 0.8 percent target phosphorus concentration, mean dissolved phosphorus removal ranged 86 to 98 percent for the amended cells compared to 20 percent for the control cell. In the final week of the study, with 0.8 percent target phosphorus concentration in the artificial stormwater, percent removal of dissolved phosphorus was 82 percent for the 3 percent amendment, 97 to 98 percent for the 5, 10, and 17 percent amendments, and 11 percent for the control. These results demonstrate that the Sorbtive® Media maintained high phosphorus adsorptive capacity throughout the study, especially at the 5 percent and greater amendment levels.”

Researchers estimate that the lifespan for Imbrium should be at least 10 to 30 years, depending on P loading and performance goals (Garbon, 2013 personal communication; Contech Engineering, 2013). Contech Engineering (2013) estimated 45 percent dissolved P removal at 20 years after initial installation of 5 percent Sorptive media by volume.

Field studies with Imbrium are also underway in Wisconsin (Bannerman, 2013 personal communication). Additionally, Imbrium media has been used in an upflow filter on a North Carolina wet pond, resulting in greater than 80 percent removal of dissolved P during ten monitored storm events (Winston, 2013 personal communication).

To our knowledge, no field installations with Imbrium Sorptive®MEDIA have been monitored long term. Field studies to monitor long term performance of bioretention with P sorbing amendments are recommended to monitor clogging potential and P reduction performance over the bioretention lifespan.

Examples of other innovative applications

Using P-sorptive amendments to reduce effluent P content from BMP’s is a newly emerging field. Some applications of P-sorptive amendments that are promising but for which there is not sufficient research to recommend them as standard practices are discussed below.

Using by-products like gypsum, mining residuals, or drinking water treatment residuals in filters

Several researchers have developed ditch filters with P-sorbing materials to intercept surface and subsurface flow ditch water to trap dissolved P. The filters can be replaced as needed when the P-sorption sites are full (Schneider, 2013; Stoner et al., 2012). They report that “Overall, by-products that are elevated in oxalate Al or Fe, WS Ca [water soluble calcium], and BI [buffer index] serve as the best P sorbents in P removal structures, and screening for these properties allows comparison between materials for this potential use. The flow-through approach described in this paper for predicting design curves at specific [retention time] and inflow P combinations aids in predicting how much P can be removed and how long a specific material will last until P saturation if the P loading rate for a specific site is known." (Stoner et al., 2012)

Researching the use of such filters on effluent from bioretention systems is recommended, as this would likely be an effective technique for P reduction in bioretention systems on projects where use of filters and ability to replace them as needed is realistic and desirable. For research on by-products, testing of composition and leaching of potentially harmful chemicals (e.g. dissolved metals) should be undertaken to ensure public health.

Using drain pipes enveloped in Fe-coated sand

Groenenberg et al. (2013) tested the performance of a pipe drain enveloped with Fe-coated sand, a side product of the drinking water industry with a high ability to bind P from the (agricultural) drainage water. They report that "The results of this trial, encompassing more than one hydrological season, are very encouraging because the efficiency of this mitigation measure to remove P amounted to 94 percent. During the trial, the pipe drains were below the groundwater level for a prolonged time. Nevertheless, no reduction of Fe(III) in the Fe-coated sand occurred, which was most likely prevented by reduction of Mn oxides present in this material. The enveloped pipe drain was estimated to be able to lower the P concentration in the effluent to the desired water quality criterion for about 14 years. Manganese oxides are expected to be depleted after 5 to 10 years. The performance of the enveloped pipe drain, both in terms of its ability to remove P to a sufficiently low level and the stability of the Fe-coated sand under submerged conditions in the long term, needs prolonged experimental research." Application of this technique could also potentially be effective for reducing P in effluent from bioretention systems with underdrains. Unlike the filter application described in Schneider (2013), though, the iron around the pipe cannot easily be removed and replaced when the P binding sites are full. However, depending on P, Ca, and iron concentrations, there may be enough P sorption sites to last the lifespan of the bioretention system. This application is similar to bioretention systems currently being tested by Bannerman in Wisconsin (Bannerman, 2013 personal communication)

Rototilling Water Treatment Residuals into existing bioretention facilities

O'Neill and Davis (2012b) also suggest that established bioretention facilities could be retrofitted for increased P reduction by rototilling WTRs into the media, as agricultural surface application has been shown to be effective. Bioretention facilities may need to be re-planted after roto-tilling WTRs into the media, however, as rototilling would likely damage roots of existing vegetation. Alternatively perhaps a different way could be found to incorporate WTRs into existing bioretention facilities, such as, perhaps by air spading out some of the existing soil around existing vegetation, and replacing the soil that was removed with bioretention soil media amended with WTR's. This technique could perhaps be used to renew P sorption capacity of bioretention facilities when P sorption sites are filled.

Applicability

- Removal of dissolved phosphorus requires a comparatively high hydraulic retention time, and therefore a deeper media (Hsieh et al., 2007 in Hunt et al 2012). Media depth should therefore be at least 0.6 meters, with 0.9 meters recommended (Hunt et al., 2012).
- Infiltration rates between 0.007 and 0.028 millimeters per second (1 to 4 inches per hour) work best, as this increases the hydraulic retention time, allowing for more sorption to occur (Hunt et al 2012).
- If the media is saturated where phosphorus is stored, P is likely to leach out. So if an internal water storage (IWS) layer is used, it should be located below the P-sequestering portion of the media. Therefore, a 0.45 to 0.6 meter (1.5 to 2 foot) separation is recommended between the top of the IWS layer and the media surface (Hunt et al 2012). The P-sorptive amendment should be located at least 0.5 feet above the top of the IWS zone (Winston, 2013).

Life cycle properties

P sorptive amendments have been shown to provide effective P retention for the expected lifetime of bioretention facilities (e.g. Lucas and Greenway, 2011; O'Neill and Davis, 2012a and 2012b).

Maintenance needs

Soil amendments to enhance P sorption typically do not increase bioretention maintenance needs. Water treatment residuals (WTR's) are fine textured, so systems with WTR's should be designed to minimize clogging. Hinman and Wulkan (2012) recommend adding shredded bark at 15 percent by volume for each 10 percent WTRs added by volume to compensate for the fine texture of WTRs.

Iron filings can be obtained with a size distribution similar to sand. Erickson et al (2012) found that hydraulic conductivity of a sand filter was not negatively affected when operated for a year with up to 10.7 percent iron filings, which is enough iron to capture a significant percent of dissolved P.

Cost information

Soil amendments to enhance P sorption are a relatively low cost technique to improve long term dissolved P removal. Steel wool, for example, has been found to increase the material cost by 3 to 5 percent (Erickson et al., 2007). Iron filings cost less than steel wool per unit weight because they require less manufacturing to produce (Erickson et al., 2012). Since WTRs are byproducts of the water treatment process, they can often be procured for little or no cost.

References

- Agyin-Birikorang, Sampson, George A. O'Connor,Lee W. Jacobs, Konstantinos C. Makris, and Scott R. Brinto. 2007. *Long-Term Phosphorus Immobilization by a Drinking Water Treatment Residual*. J. ENVIRON. QUAL. 36:1:316-323.
- Beck, D.A., G.R. Johnson, and G.A. Spolek. 2011. *Amending green roof soil with biochar to affect runoff water quantity and quality*. Environmental Pollution 159(2011):2111-8.
- Buda, A.R., G. F. Koopmans, R. B. Bryant, and W. J. Chardon. 2012. *Emerging Technologies for Removing Nonpoint Phosphorus from Surface Water and Groundwater: Introduction*. J. Environ. Qual. 41:621–627.
- Chardon, W.J., J. E. Groenenberg, E. J. M. Temminghoff, and G. F. Koopmans. 2012. *Use of Reactive Materials to Bind Phosphorus*. J. Environ. Qual. 41:636–646.
- Contech Engineering. 2013. Sorbtive® Media AI 28x48 for Phosphorus Treatment. Application: Bioretention Soil Amendment 20-Year Service Life Performance Estimates (http://www.slideshare.net/ContechES/maximizing-phosphorus-load-reduction).
- Erickson, A., J. Gulliver, and P. Weiss. 2007. Enhanced Sand Filtration for Storm Water Phosphorus Removal (https://www.pca.state.mn.us/sites/default/files/stormwaterresearch-sandfiltration.pdf). J. Environ. Eng. 133(5), 485–497.
- Erickson, A. 2010. *Iron Enhanced Sand Filtration For Stormwater Phosphorus Removal*. Presentation given February 23rd, 2010.
- Erickson, A.J., J.S. Gulliver, and P.T. Weiss. 2012. *Capturing phosphates with iron enhanced sand filtration*. Water Research. 46(9): 3032–3042.
- Groenenberg JE, W.J. Chardon, G.F. Koopmans. 2013. *Reducing phosphorus loading of surface water using iron-coated sand*. Journal of Environmental Quality. 42(1):250-9.
- Hinman, C., and B. Wulkan. 2012. Low Impact Development. Technical Guidance Manual for Puget Sound (http://www.psp.wa.gov/downloads/LID/LID_manual2005.pdf). Publication No. PSP 2012-3.
- Hunt, W., Davis, A., and R. Traver. 2012. *Meeting Hydrologic and Water Quality Goals through Targeted Bioretention Design*. J. Environ. Eng. 138(6): 698–707.

- Kawczyinski, E., Achtermann, V. 1991. *A water industry database report on residuals handling*. In Proc. of the AWWA/WEF Joint Residuals Conf. Durham, NC. 11-14 Aug. American Water Works Association. Denver, Colorado. p. 6b-1 to 6b-5.
- Lucas, W. C. and M. Greenway. 2011. *Phosphorus Retention by Bioretention Mecocosms Using Media Formulated for Phosphorus Sorption: Response to Accelerated Loads*. Journal of Irrigation and Drainage Engineering. 137(3): 144-152.
- O'Neill, S. W., and A. P. Davis, A. P. 2012a. *Water treatment residual as a bioretention amendment for phosphorus. I. Evaluation studies*. J. Environ. Eng. 138(3): 318–327.
- O'Neill, S. W., and A. P. Davis. 2012b. *Water treatment residual as a bioretention amendment for phosphorus. II. long-term column studies*. J. Environ. Eng., 138(3), 328–336.
- Schneider, C. Re-using byproducts in agricultural fields. 2013.CSA News. Crop Science Society of America, Soil Society of America, American Society of Agronomy. April 2013 issue.
- Stoner, D., C. Penn, J. McGrath, and J. Warren. 2012. *Phosphorus Removal with By-Products in a Flow-Through Setting*. J. Environ. Qual. 41:654–663.

Related pages

- Overview for trees
- Types of tree BMPs
- Plant lists for trees
- Street sweeping for trees
- References for trees
- Supporting material for trees

The following pages address incorporation of trees into stormwater management under paved surfaces

- Design guidelines for tree quality and planting - tree trenches and tree boxes
- Design guidelines for soil characteristics - tree trenches and tree boxes
- Construction guidelines for tree trenches and tree boxes
- Protection of existing trees on construction sites
- Operation and maintenance of tree trenches and tree boxes
- Assessing the performance of tree trenches and tree boxes
- Calculating credits for tree trenches and tree boxes
- Case studies for tree trenches and tree boxes
- Soil amendments to enhance phosphorus sorption
- Fact sheet for tree trenches and tree boxes
- Requirements, recommendations and information for using trees as a BMP in the MIDS calculator
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This page was last edited on 17 April 2020, at 12:22.

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