Vegetated Bioretention Mesocosms

Dynamics In Vegetated And Non--

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Nitrogen Retention with Depth

In bioretention systems, the removal of nutrients are more complex than metals.

Nitrogen is found as nitrate (NO₃) and Total Kjehldahl Nitrogen (TKN), which includes organic forms (ON), both particulate and dissolved, plus ammonium (NH₄). Most ON will mineralize into ammonium. Ammonium is then nitrified into nitrate, as well as reversibly adsorbed to media. Nitrate is not adsorbed at all, and flushes out readily.

Nitrogen is not adsorbed at all, and flushes out readily. Ammonium is then nitrified into nitrate, as well as reversibly adsorbed to media. Ultimately though, the binding sites become saturated, and there will be no more adsorption of NH₄. As a result, P removal efficiency increases with depth. Eventually though, the binding sites will become saturated, and there will be no more adsorption of PO₄. This is a major issue in the long term performance of bioretention systems.

The Effect of Vegetation

A study by Denman et al. (2006) further confirms that bioretention systems without plants do not perform nearly as well as systems with plants. See results below from Henderson et al. (2005). Note how all media except sand perform well for NH₄, regardless of presence of plants. Curves show that sand media becomes readily saturated. On the other hand, plants have a very substantial effect upon NO₃ retention in all media types compared to mesocosms without vegetation.

Phosphorus Retention with Depth

In the case of Phosphorus (P), there are also particulate and dissolved forms. Most Particulate P is not biologically available, although there can be a considerable organic component that eventually breaks down and becomes a stressor. Dissolved P is mostly ortho-phosphate (PO₄), which is very readily taken up by plants and nuisance algae in lakes and streams. PO₄ is readily adsorbed onto media substrates such as iron and aluminum sesquioxides on clay particles, as well as calcium complexes. These reactions operate with varying degrees of speed and reversibility. As a result, P removal efficiency increases with depth.

Effects of Vegetation

Vegetation is remarkably effective in restoring and/or enhancing infiltration rates. Rates in undisturbed vegetated areas can be up to several orders of magnitude higher than underlying soil.

Vegetation roots penetrate confining layers, and provide habitat for worms and other fauna to create macropores, opening up soil structure. Root turnover promotes the formation of micropores. Root exudates promote growth of microbes and mycorrhizal fungi, which add organic matter, promoting increased uptake of nutrients and metals.

Native grass hedges in crop fields not only accumulate very substantial sediment (~70%), but their infiltration rate was nearly an order of magnitude higher than the adjacent cropped area. It appears that the deeper the root growth, the better, so native grasses (to 100 cm) should be much better than turf (to 20 cm).
The Effect of Vegetation on P

Henderson et al (2006) found similar results for PO<sub>4</sub>, where the affect of plants is clearly discernible in the loam and gravel treatments. Retention increases by an order of magnitude.

In this case, the sand media without plants is just as good as that with plants. This suggests that the sand media has still has lots of axon sorption capacity, but not much cation adsorption (for ammonium).

However, the response by media alone in the unvegetated systems indicates that the media has higher equilibrium concentrations than observed in the loam.

Sorption experiments show that longer retention time (72 hours) lowers the hydraulic conductivity over a 6 hour period.

Infiltration rates decline within first hour, when compared to unvegetated systems. This organic matter may be involved in the short term.

Loam Mesocosms show high initial infiltration rate, due to unsealed hydraulic conductivity over a 6 hour period. Drainage hydrographs show a backwater effect to peak, with over a day to fully drain.

Vegetated systems are controlled by understory shedding, which is most attributable to the revegetated systems. Note how vegetated control has highest flow rate. Despite no clogging, as shown in the hydrograph, while the rest show an initial increase time, typical of an outlet controlled hydrograph.

Loganholme WWTP

Mesocosms are 240 liter “wheelie bins” with 3 different media treatments:

- 80cm Sandy Loam (8% clay)
- 80cm Loamy Sand (4% clay)
- 20cm Loamy Sand and 60cm Gravel

Half of the mesocosms are vegetated with a mix of shrubs and grasses. Other half have gravel only.

Influent is a mix of domestic wastewater, municipal, distributed by irrigation drippers. Inflow regulated through inlet pipe.

Effluent collected in long chambers of 10mm pipe.

Chambers placed on scales to record flows.

Thanks to Vidsteed for the chambers!

A Subtropical Setting

Mesocosm setup

Mesocosm Hydraulics

Without outlet controlled, sand mesocosms had initial infiltration rate, but not to maximum. Drainage hydrographs of 5/7-7/8 showed substantial flow from a whole month with only 6 hours to completely drain.

Outlet control allows phases in the 0-24 runs, resulting in infiltration rates that decline to the putting a control rate over a 2 hour period.

Note that there is a “backwater” effect, as infiltration rates decline within first hour, when voids are still not totally saturated.

Overall discharge hydrographs similar to others.
Phosphorus Response-Dosing

- Orthophosphate shows a major response to media type, with low-being scores, and unusual liking, across all systems.
- Nutrient reduction is substantially in all vegetated systems.
- Organic P shows less pronounced media response. Again, note substantial reduction in vegetated systems.
- Total P response shows less overall effect of vegetation in 20cm sand, but cumulative reduction in vegetated and substrates without plants.
- Note further very substantial reductions in all vegetated systems.

Response to N Loading

- Following initial dosing results, experiment now examines the long term effectiveness of the systems.
- No is accumulated by leaching with tertiary effluent at high concentrations (up to 8 mg/ L) in P. Sand is advertised approximately on three typical annual load of P and N. Initial analysis shows little difference. Nitrate and effluent water remaining 89% of original, with minimal nitrogen uptake, allowing for a lot of nitrate leaching.
- Vegetation reduction is significant in all media types. Inorganic plant uptake is significant compared to other systems.
- In the case of sand media, there is little effect with minimal retention. However, vegetation uptake retention up to 60% in sand, and 80% in the plant. Note how N retention increases as the system matures. Reactivated sand measures perform better.
- Note how N retention is an inverse function of solute concentration. In that lower concentrations result in increased retention, while higher concentrations are less effectively retained.

Bioretention Hypothesis

- Preliminary mass balance computations suggest that the observed N and P retention is not solely due to plant uptake, since typical plant uptake ratios comprise only 10%-15% of the N and P applied.
- Experiments in plants indicate that plants transpire 10%-15% of the hydraulic load, so this seems to be a reasonable conclusion.
- Microbial biomass in another uptake pool, and plants do increase soil organic matter (rhizosphere biomass) by an order of magnitude compared to substrates without plants.
- However, even though soil immobilization processes would perhaps more than double observed uptake, there is still a substantial mass of P retention that is not accounted for.
- Therefore, it seems that most of the P does end up being retained by the media, even though it seems to move through too rapidly for the observed effluent reported.
- The role of plant and microbial biomass seems to be:
  1. Temporarily retain orthophosphate within the profile, so that it does not leach deeper into the profile under a longer time frame.
  2. Provide a carbon source for denitrification to occur in a longer time frame of the profile even extending to aerobic conditions.

QUESTIONS?

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