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ROLE OF PHYTOREMEDIATION IN NUTRIENT REMOVAL FROM RUNOFFS FOR LIGHT-WEIGHT MEDIA

Kien Tat Wai[a], Stephen McNally[b], Courtenay Bremner[b] and Lokesh P Padhye[a]

[a]*Department of Civil and Environmental Engineering, University of Auckland*
[b]*WSP-OPUS NZ, Level 9 Majestic Centre, 100 Willis Street, Wellington*
Email: l.padhye@auckland.ac.nz

Abstract

Concerns have been raised regarding nutrient leaching from agricultural soils due to excess use of fertilisers and high intensity animal grazing systems. High concentration of these nutrients, nitrogenous compounds and orthophosphates, upon discharge to receiving water bodies can lead to eutrophication and other negative environmental consequences. Hence, reducing nutrient losses via leaching and surface flow by applying a suitable choice of soilless growing media is one of the possibilities. This study focuses on the development of locally obtained, light-weight media mix which not only allows satisfactory growth of plant's root system, thus supporting vegetation, but also aids in mitigating nutrient leaching. The current stage of the study involved unvegetated column experiments, which tested pollutant removal performance on two combinations of the five different light-weight media components in the presence of green compost: perlite, vermiculite, activated carbon, zeolite, and coconut coir. Our findings indicated that there was a significant removal of ammonium, nitrite, and nitrate through these media mixes. Ammonium and nitrite were removed by more than 90% in all trials, while minimum nitrate removal was recorded at more than 70%. Orthophosphate removal could not be quantified due to leaching of phosphorus from the media in the initial run.

Keywords: nutrient leaching, light-weight media, phytoremediation, soilless, runoff

Introduction

Potential of phytoremediation approaches has been increasingly studied globally since mid-nineties yet is still rarely applied in remediation practice due to lack of deep understandings in methods' functionality, lack of convincing pilot applications & untested emerging sustainable technology (Bleicher, 2016). In general, phytoremediation is a solar-driven technology used in a wider context in one of the Low Impact Developments (LIDs). LID, a 'green infrastructure' engineering design practices such as bioretention systems, is an increasingly popular technique to manage runoff similar to on-site natural processes (Chahal, Shi & Flury, 2016). Bioretention (biofilter) operates by filtering runoff through porous media, planted with vegetation (Hsieh & Davis, 2005) and provide treatment via fine filtration, extended detention and biological uptake (Bratieres, Fletcher, Deletic & Zinger, 2008).

Runoff from agriculture plots and urban area often carries excess nutrients from fertiliser and manure that are not sufficiently removed by existing control measures or natural pasture growth requirements. According to Stats NZ (2017), there was about 2000 million kilograms of nitrogen were applied to agricultural land as fertiliser. Of the total nitrogen applied, an estimated 137 million kilograms or 7% leached from the soil. Loss directly from fertiliser accounted for 19% while the remainder was through livestock waste. Unpredictable weather lately blamed on the global warming resulting in higher rain intensity magnified the severity of nutrient leaching and surface flow, leads to water quality compromise in aquatic ecosystem. Hence, reducing nutrient losses via leaching or surface flows by applying a suitable choice of soilless growing media is one of the possibilities.

Biofilter soil media with added organic matter reduced the phosphorus treatment effectiveness (Bratieres et al., 2008). Bioretention fate of phosphorus is similar to that of metal with an opportunity for its removal via vegetation uptake or sequestration in soil media (Davis, Shokouhian, Sharma & Minami, 2006). In contrast, a small presence of compost (10% v/v) in sand biofilter was found to be important in increasing cation exchange capacity (CEC) and helped in removing Cu and Zn in synthetic stormwater runoff (Fassman, Simcock & Wang, 2013). A review of literature revealed little attempts on the application of light-weight media in bioretention system. Studies of other vegetated filtration systems; green walls (Prodanovic, Hatt, McCarthy, Zhang & Deletic, 2017) and green roofs (Kuoppamäki & Lehvävirta, 2016) have demonstrated that light-weight media plays an important role in supporting plant growth while facilitates primary removal of sediments, nutrients and heavy metals. Past studies involved sand and gravel filter with vegetation shown promising results in reducing contaminants in stormwater (Hsieh & Davis, 2005; Bratieres et al., 2008)

Fassman et al. (2013) recommended several bioretention media mixes that are suitably used worldwide (sand, sandy loam and silt) but the challenging part is still due to their greater weight imposed on the overall bioretention structure and bulk handling. Therefore, the aim of this study was to develop a locally obtained, light-weight media mix that not only allows satisfactory growth of plant's root system, thus supporting vegetation, but also aids in mitigating nutrient leaching. In this study, investigation on the removal efficiency of nutrients from semi-natural runoff by two media mixes were carried out.

Materials and Methods

The study was conducted using two different columns; ten PVC biocolumns (Biocolumns 1, ID: 54 mm) with a total height of 410 mm for most media and one PVC biocolumn 2 (ID: 75 mm) of a total height 405 mm for coco coir media only. A total volume of 80% was allocated for media filling while the remaining 20% was for extended ponding depth. At the bottom of each biocolumn, a layer of 2.5 mm square plastic mesh was installed to reduce media loss during runoff dosing process.

Material characteristics

Five different light-weight media were selected based on their weight, water retention capacity, porosity, capability of supporting vegetation, sustainability and local availability. These media that were used in the study are perlite, vermiculite, activated carbon, zeolite and coco coir. Their characteristics are shown in Table 1 below. Green compost is an addition to the existing media as it is known to support plant growth by increasing its cation exchange capacity (CEC) (Fassman et al., 2012). However, presence of organic matter in the study is limited to 10% w/w as suggested in Burge et al. (2007) in order to avoid potential of serious nutrient leaching.

Table 1: Physical characteristics of the selected light-weight media and green compost.

Media	Properties	Size (mm)	Dry bulk density (kg/m^3)
Perlite	Ausperl - Expanded perlite, P500 coarse	As sourced	90
Vermiculite	Ausperl - Vermiculite, Three medium	As sourced	141
Activated carbon	Acticarb GC1200 - 4 x 8 mesh granulated activated carbon	1.18 – 4.75	488
Zeolite	Zeolite Filta aid, normal application in water treatment	1.2 – 4.0	580
Coco coir	Coco Professional Plus - Fibrous and finely ground	1.18 – 4.75	91
Green compost	1-2 years open-composting	1.18 – 4.75	632

Two media mixes with three replicates each were prepared; MM1 that contains coco coir with the addition of compost, activated carbon and zeolite while MM2 contains all media highlighted in the Table 1. A control each for five different individual media; perlite (Control-P), vermiculite (Control-V), activated carbon (Control-Ac), zeolite (Control-Z) and coco coir (Control-C) were also prepared and tested against MM1 and MM2. All media for each column were mixed well prior to filling into the respective biocolumns. Light tapping (10x) was done on the media in each biocolumn at every 5 cm depth. A layer of 1 mm square stainless steel mesh was installed on top of the finished media in each biocolumn to prevent scouring effect during runoff dosing.

Column study: Runoff dosing

A semi-natural runoff of the following characteristic was prepared; ammonium (0.42 mg/L), nitrite (0.54 mg/L), nitrate (3.19 mg/L) and orthophosphate (1.45 mg/L). Soil of 600 micron or less was sieved (Hsieh & Davis, 2005) and later used to prepare runoff stock solution with a suspended solid concentration of 80 mg/L. Semi-natural runoff was prepared by adding pre-calculated salt solutions of ammonium, nitrite, nitrate and orthophosphate into the runoff stock solution before transferred to the runoff dosing system.

Runoff dosing system consists of a rectangular square-based runoff distribution tank (150 mm x 150 mm x 185 mm), tubing system (ID: 3 mm) and gardening hose water flow control switch. Ten tubes with each fixed flow control switch were connected to the bottom of the distribution tank to deliver a flowrate of 189 ml per hour to the respective biocolumns. Meanwhile, Biocolumn 2 (coco coir only) was installed separately with a higher flowrate of 365 ml per hour since its surface area is proportionally larger than Biocolumns 1. The depth of water in the distribution tank was maintained at 5.5 cm to ensure consistent flow of runoff by gravity to each Biocolumn 1. Mixing in the distribution tank was provided by stirrer (Model IKA RW20 digital) at 100 rpm throughout the study. Prior to actual runoff dosing, flushing with Ultrapure Type 1 water (according to designated flowrate) was done four times with 2 days interval between each flushing phase. Runoff dosing phase was conducted later for seven times within 21 days period.

Sampling and data analysis

Effluent samples from each biocolumn were collected in a 500 ml beaker for each successful run. Sampling of effluent was only conducted during the runoff dosing phase for temperature, pH and nutrient analysis. Measurement of pH and temperature was done with pH meter, Hach HQ40d while ammonium was analysed using Phenate Method (APHA, 2012). Measurement of nutrients such as nitrite, nitrate and orthophosphate were conducted using Ion Chromatography (IC), Thermo Scientific Dionex ICS-2100.

Results and discussion

Temperature of the effluent samples during the study were recorded in between 20 and 24 degrees Celsius. Effluent for media mix MM1 and MM2 shown average pH of 8.28 and 8.06 respectively, mainly due to the presence of activated carbon (Mohammed, Vigneswaran & Kandasamy, 2011) and partially contributed by the leaching of base cations from compost (Chahal et al., 2016). Average pH results for other controls were as follows; perlite (7.82), vermiculite (8.20), activated carbon (8.93), zeolite (7.98), coco coir (7.70) while average pH for the runoff was 7.84.

All biocolumns including media mix (MM1 and MM2) and controls able to achieve minimum 90% ammonium removal. The result indicated that all media produced effluent of less than 0.05 mg/L of ammonium after intermittent dosing within 21 days period. Lower removal was observed for MM1 and MM2 as ammonium leaching from the compost in both media mix contributed to its presence in the effluent. A similar trend was also observed for coco coir control as Prodanovic et al. (2017) reported a range of 35 – 75% removal for total nitrogen in their green wall for greywater reuse study. It seems that coco coir needs intermittent wet and dry period to develop significant biofilm for better reduction of nitrogenous compounds.

Average nitrite concentration of the runoff was measured at 0.54 mg/L. Both media mix of MM1 and MM2 able to remove nitrite by 98% and few other controls; Control-Ac and Control-C also demonstrated the same capability. However, some controls unable to perform as good as the media mix; Control-P, Control-V and Control-Z produced relatively high nitrite due to lack of removal capability by the respective media.

Nitrate removal observed in various soilless media as well. The average nitrate concentration of the prepared runoff was 3.19 mg/L. Media mix MM1 and MM2 shown moderate nitrate removal of 88 and 74% respectively. MM1 performed better than MM2 as it contains higher mass of activated carbon that is effective in removing nitrogenous compounds such as nitrite and nitrate (Al-Anbari et al., 2008; Mohtadi et al., 2017) and this result was strongly supported by the performance of activated carbon as control (Control-Ac). Moreover, both mix media also contains significant amount of coco coir that contributed to the reduction of nitrate as observed in Control-C (Prodanovic et al., 2017). In contrast, Control-P, Control-V and Control-Z were not designed to remove nitrate in the stormwater. This is evidenced from the graph where removal capability of those controls was low.

Unfortunately, orthophosphate removal was not observed for the mix media MM1 and MM2. Instead, presence of activated carbon in the mix media resulted in high orthophosphate leaching (Al-Anbari et al., 2008; Mohtadi et al., 2017) while compost and coco coir played a minor role in the leaching. Higher percentage of activated carbon in the MM1 than MM2 mix media caused more orthophosphate leached from the media. Other controls except Control-Ac in general either produced very low orthophosphate or exhibited absence of orthophosphate in the sample collected (indicated by positive value reduction). Meanwhile, as expected Control-Ac produced a large amount of orthophosphate leaching (Mohtadi et al., 2017) and the leaching for Control-Ac could be higher since four runs of flushing using ultrapure Type 1 water had been conducted prior to the runoff dosing.

Conclusions

The current stage of the study involved the first stage of the column experiments – unvegetated biocolumns, which tested pollutant removal performance on two combinations of the five different light-weight media components in the presence of green compost: perlite, vermiculite, activated carbon, zeolite, and coconut coir. Our findings indicated that there was a significant removal of ammonium, nitrite, and nitrate through these media mixes. Ammonium and nitrite were effectively removed by 94% and 98% respectively in all trials, while minimum nitrate removal was recorded at 74%. Orthophosphate removal could not be quantified due to leaching of phosphorus from the media in the initial run.

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