Science of the Total Environment 569–570 (2016) 123–133

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Phosphorus removal from secondary sewage and septage using sand media amended with biochar in constructed wetland mesocosms

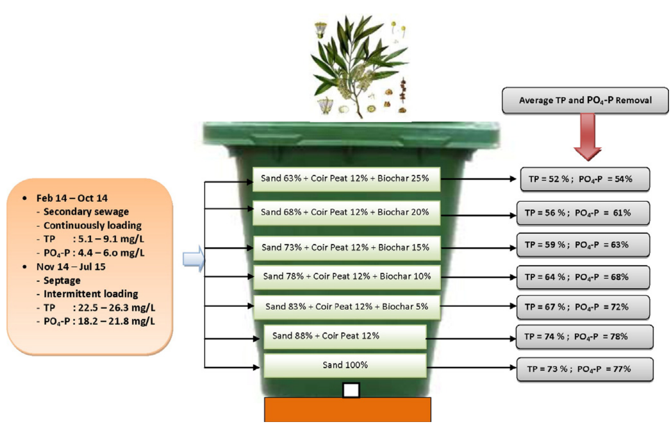
P. de Rozari [a,b,*], M. Greenway [a], A. El Hanandeh [c]

[a] Griffith School of Engineering, Griffith University, Environmental Futures Research Institute Griffith Sciences, Nathan, Brisbane, Australia
[b] Department of Chemistry, Faculty of Science and Engineering, Nusa Cendana University, Kupang, Indonesia
[c] Griffith School of Engineering, Griffith University, Nathan, Brisbane, Australia

HIGHLIGHTS

- Phosphorus removal efficiency were inversely related to the biochar content of media.
- Sand amended with biochar is less effective in removing P than pure sand.
- Presence of biochar encouraged microbial P activity.
- The most microbial P activities occurred in the upper 20 cm of media.
- Total biomass P in pure sand was higher than sand amended with biochar.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 April 2016
Received in revised form 14 June 2016
Accepted 14 June 2016
Available online xxxx

Edited by: Sarmah Ajit

Keywords:
Biochar
Biomass
Cymbopogon citratus
Melaleuca quinquenervia
Phosphorus

ABSTRACT

To improve the performance efficiency of subsurface constructed wetlands (CWs), a variety of media have been tested. Recently, there has been a rising interest in biochar. This research aims to develop the effectiveness of sand media amended with biochar and two plants species (*Melaleuca quinquenervia* and *Cymbopogon citratus*) in removing phosphorus from sewage effluent in CWs. The experimental design consisted of vertical flow (VF) mesocosms with seven media treatments based on the proportions of biochar in the sand media which ranged from 0 to 25% by volume. During the first 8 months, the mesocosms were loaded with secondary clarified wastewater (SCW) then septage was used for the remaining 8 months. Inflow and outflow were monitored for total phosphorus (TP) and PO_4-P. Plants were harvested at the end of the experiment and TP biomass was determined. Removal efficiencies of TP in the mesocosms loaded with SCW and septage ranged from 42 to 91% and 30 to 83%, respectively. Removal efficiencies of PO_4-P ranged from 43 to −92% and 35 to 85% for SCW and septage, respectively. The results revealed that the sand media performed better than the biochar-amended media; increasing the proportion of biochar in the media decreased removal efficiency of phosphorus. However, after flushing due to major rain event, there was no significant difference between sand and sand augmented with 20% biochar.

Abbreviation: AEC, anion exchange capacity; BOD, biological oxygen demand; C, carbon; CEC, cation exchange capacity; CP, coir peat; CW, constructed wetland; DSTC, digested sugar beet tailing; FTIR, Fourier transform infra-red; HC, hydraulic conductivity; HRT, hydraulic retention time; OM, organic matter; P, phosphorus; SCW, secondary clarified wastewater; TN, total nitrogen; TP, total phosphorus; TSS, total suspended solids; VF, vertical flow; VFCW, vertical flow constructed wetlands; WTR, water treatment residuals.

* Corresponding author.
E-mail addresses: phderozari@yahoo.com, philiphi.derozari@griffithuni.edu (P. de Rozari), m.greenway@griffith.edu.au (M. Greenway), a.elhanandeh@griffith.edu.au (A. El Hanandeh).

http://dx.doi.org/10.1016/j.scitotenv.2016.06.096

Secondary sewage
Septage

Total plant P ranged from 1.75 g in the 20% biochar mesocosm to 2.10 g in the sand only mesocosm. Plant uptake of P, at least in part, may be accredited for the better P removal efficiency in the sand media compared to the biochar-amended media.

1. Introduction

Eutrophication of fresh water bodies is one of the main problems facing aquatic ecosystems. In developing countries, approximately 75% of domestic wastewater is released to the environment without treatment (Kurniadie 2011, Westholm 2006). Ayaz et al. (2012) reported that eutrophication in receiving water bodies may occur when phosphorus concentrations are >6 mg/L. Therefore, proper treatment to remove phosphorus from domestic wastewater to achieve the admissible level for natural systems is needed.

Constructed wetlands (CWs) are easy to implement ecotechnologies which have been proven as efficient technologies for wastewater treatment. Constructed wetlands are also known for offering low cost, simple operation and low maintenance wastewater treatment solution (Kadlec and Wallace 2008). Although, CW technologies are efficient in removing biological oxygen demand (BOD) and total suspended solids (TSS) from wastewater (Abou-Elela et al. 2013, De Rozari et al. 2015), phosphorus removal is still a challenge (Ayaz et al. 2012).

Different materials have been used as a media to enhance and enable long term phosphorus removal in CWs; for example: (1) natural material such as zeolites, dolomite, gravels, sands, limestone and apatite, (2) man-made products, such as filtralite, alunite, norlite, and (3) by products such as red mud, fly ash, and slag (Vohla et al. 2011). Arias et al. (2001) stated that sand mainly would be effective in removing phosphorus only for a few months in full scale systems. However, Vohla et al. (2011) reported long term purification of phosphorus utilizing sand media. Lucas and Greenway (2010) found that sand amended with red mud and water treatment residuals improved long term phosphorus removal from secondary effluent.

Lately, there has been a rising interest in biochar as a potential alternative media for wastewater treatment. Biochar is carbon-rich product obtained by the thermochemical decomposition of biomass in the absence of oxygen or under depleted oxygen conditions (Hossain et al. 2011, Manya 2012). Based on laboratory experiment, Yao et al. (2011) reported that biochar prepared at 600 °C from digested sugar beet tailing (DSTC) had better phosphate removal ability (73%) than activated carbon prepared from coconut shell. Batch sorption experiment with different shaking times (1, 8, 24 h and 1 week) conducted by Sarkhot et al. (2013) showed that hardwood-biochar prepared via slow pyrolysis (at 300 °C and residence time 8–12 h) can absorb 50% and 96% of PO_4^{3-} solution from manure and synthetic solution, respectively. Chintala et al. (2014) compared *P*-sorption efficiency of different types of biochar prepared in fast pyrolysis process at 650 °C and reported that the P-sorption efficiency of biochar of corn stover (*Zea mays* L.) and switchgrass (*Panicum virgatum* L.) were 79% and 76%, respectively. These findings suggest that biochar may enhance phosphorus removal from wastewater and may provide a low cost media amendment for improving the performance of CWs. Limited literature is found about the effect of biochar on the performance of constructed wetlands to remove phosphorus from wastewater (Gupta et al. 2015). However, these studies were conducted in controlled laboratory scale environment and mostly using synthetic wastewater. Therefore, the objective of this study was to investigate the efficiency of biochar as media amendment in VFCWs for phosphorus removal at mesocosm scale subjected to natural environmental conditions. To the best of the authors' knowledge this is the first study conducted at mesocosm scale to investigate the effect of sand media amendment with biochar on the performance of constructed wetland to remove phosphorus from actual secondary treated wastewater and raw septage under natural environment conditions.

2. Methods

2.1. Experimental design

The experiments were carried out from November 2013 through July 2015 at the Loganholme Water Pollution Control Centre, 40 km south of Brisbane in South East Queensland. Seven treatments with different biochar content were setup (Table 1). All treatments were triplicated. In total, there were 21 vertical flow (VF) mesocosm bins made of plastic containers measuring 0.5 m × 0.5 m × 0.98 m (240-l). Fig. 1 shows a schematic diagram of the mesocosm setup. More detailed description of the experimental setup can be found in de Rozari et al. (2015).

The mesocoms were planted with one *Melaleuca* tree (*M. quinquenervia*) and one lemongrass (*C. citratus*) each. The selection of *Melaleuca* was based on their (1) ability to tolerate inundation; (2) high potential biomass sink for nutrients; (3) high rates of litter fall but slow decomposition; and (4) endurance in extreme conditions i.e. salinity, alkalinity, acidity (Bolton and Greenway 1997); Lemongrass (*C. citratus*) is a perennial grass which is widely cultivated in tropical countries and was selected due to its effectiveness to reduce suspended solids (Wanyama et al. 2012) and its economical value particularly for traditional medicine (Ekpenyong et al. 2015).

The experiment was conducted in three phases over a period of 21 months between November 2013 and July 2015 as shown in Table 2. The wastewater was obtained from Loganholme Water Pollution Control Centre and stored in 5000 L tanks. Each tank distributed the effluent to seven treatment mesocosms and was topped up with new effluents every month.

Table 1
Percentage and characteristic of media in the mesocosm system.

Media	Percentage of media (%)			pH	% OM	CEC cmol(+)/kg	AEC cmol(−)/kg	Range of HC (cm/h)
	Sand	Biochar	CP					
S100	100	–	–	6.79 ± 0.02	0.36 ± 0.02	5.73 ± 0.54	1.09 ± 0.05	94–108
SCP	88	–	12	6.74 ± 0.01	0.63 ± 0.08	5.90 ± 0.26	–	93–103
BC5	83	5	12	6.81 ± 0.01	1.28 ± 0.07	6.85 ± 0.54	1.31 ± 0.04	82–87
BC10	78	10	12	6.88 ± 0.01	2.21 ± 0.08	7.55 ± 0.30	1.40 ± 0.11	81–87
BC15	73	15	12	6.99 ± 0.01	3.37 ± 0.11	8.37 ± 0.27	1.43 ± 0.05	67–76
BC20	68	20	12	7.06 ± 0.02	4.52 ± 0.05	9.23 ± 0.35	1.51 ± 0.07	63–71
BC25	63	25	12	7.19 ± 0.02	5.55 ± 0.21	10.21 ± 0.13	1.62 ± 0.17	61–66

The hydraulic conductivity (HC) was measured on February, August 2014 and March 2015