Journal of Environmental Management 180 (2016) 517–525

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Soil amendment using poplar woodchips to enhance the treatment of wastewater-originated nutrients

Raffaella Meffe [a, *], Ángel de Miguel [b], Virtudes Martínez Hernández [a], Javier Lillo [c], Irene de Bustamante [a, d]

[a] Imdea Water, Av. Punto Com 2, 28805 Alcalá de Henares, Madrid, Spain
[b] Alterra, Department of Climate Change and Adaptive Land and Water Management— CALM, Droevendaalsesteeg, 6708 PB Wageningen, The Netherlands
[c] University of Rey Juan Carlos, ESCET, Department of Biology and Geology, C/Tulipán s/n, 28933 Madrid, Spain
[d] University of Alcalá, Department of Geology, Geography and Environment, Ctra. A-II km 33,600 28871 Alcalá de Henares, Madrid, Spain

A R T I C L E I N F O

Article history:
Received 13 March 2016
Received in revised form
24 May 2016
Accepted 31 May 2016
Available online 9 June 2016

Keywords:
Wastewater
Woodchips
Column experiment
Vegetation filter
Soil amendments
Nutrients

A B S T R A C T

Vegetation filters, a nature based wastewater regeneration technology, have been reported as a feasible solution for small municipalities and scattered populations with limited access to sewage networks. However even when such a treatment is properly planned, the leaching of contaminants through the unsaturated zone may occur. The amendment of soil with a readily-labile source of carbon is supposed to ameliorate the removal of contaminants by stimulating microbial activity and enhancing sorption processes. In this study, lab-scale leaching column experiments were carried out to explore if the addition of woodchips to the soil could be a feasible strategy to be integrated in a vegetation filter. Two different types of arrangement of soil and woodchips layers were tested. The soil was collected from an operating vegetation filter treating wastewater of an office building characterised by a high nutrient load. Daily pulse of synthetic wastewater were applied into the columns and effluent samples were collected and analyzed for major ions, total nitrogen (N_T), total phosphorous (P_T) and chemical oxygen demand (COD). By the end of the experiment, N_T, NO_3-N and P_T soil contents were also measured. Results indicate that amendments with woodchips enhance the elimination of wastewater-originated contaminants. N_T removal in the columns with woodchips reaches a value of 99.4%. The main processes responsible for this elimination are NH_4-N sorption and nitrification/denitrification. This latter fostered by the reduced redox conditions due to the enhanced microbial activity. High removal of P_T (99%) is achieved independently of the woodchips presence due to retention and/or precipitation phenomena. The COD removal efficiency is not affected by the presence of the woodchips. The leaching of organic carbon occurs only during the experimental start-up period.

1. Introduction

The excess of nitrogen and phosphorous in water resources implies problems related to eutrophication of streams, lakes, coastal waters (Ruane et al., 2011) and groundwater contamination (Knudsen et al., 2006). Sophisticated and effective technologies for water treatment have been developed and installed at the municipal treatment plants (Schipper et al., 2010a). However, their downscaling has proven inefficient due to their high cost of operation and maintenance (Ortega et al., 2011). This is the reason why operators and scientists believe that there is the necessity to develop simple, robust and low-cost strategies for small populations, to remove wastewater originated contaminants, relieving the contaminant load in the environment.

Vegetation filters, a nature based wastewater depuration technology, have been reported as a feasible solution for wastewater treatment of small municipalities and scattered populations with limited access to sewage networks (Ortega et al., 2011; de Miguel et al., 2014). However even when such a technology is properly planned, the leaching of contaminants through the unsaturated zone may occur. When wastewater is applied to the soil-plant-microbe system, contaminant leaching, especially of nitrogen and phosphorous, to shallow groundwater and ultimately to surface

---

* Corresponding author.
E-mail addresses: raffaella.meffe@imdea.com (R. Meffe), angel.demiguelgarcia@wur.nl (de Miguel), virtudes.martinez@imdea.org (V. Martínez Hernández), javier.lillo@urjc.es (J. Lillo), irene.bustamante@uah.es (I. de Bustamante).

http://dx.doi.org/10.1016/j.jenvman.2016.05.083
0301-4797/

water is an issue of great concern. In a vegetation filter not all the applied nitrogen is assimilated by plants and microbes and, in the subsurface, when nitrogen is in the form of NO_3-N it is practically not retained by soil. Indeed, the infiltration of this species through the unsaturated zone depends on the soil physico-chemical properties and on the local redox conditions. In raw wastewater such as those from septic tanks, nitrogen is mostly in the form of NH_4-N and it can be partially sorbed onto soil by cation exchange processes. Since in the unsaturated zone the redox conditions are mainly oxidizing, part of NH_4-N can be transformed to NO_3-N by nitrifying bacteria, commonly present in the soil, and infiltrates through the subsurface without further reactions. Only when conditions are anoxic, NO_3-N can be further transformed by denitrifying bacteria to N_2 gases using a carbon as the electron donor and as element for growth (heterotrophic denitrification) (Rivett et al., 2008, in Schipper et al., 2010a). On the other hand, P in wastewater is mainly in the form of orthophosphates (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, H_3PO_4) (Metcalf and Eddy, 2003). In acid soils, they are sorbed by iron and aluminium oxides. Whereas in calcareous soils, PO_4-P may precipitate as calcium phosphate ($Ca_3(PO_4)_2$) (Bouwer, 1974; Duchafour, 1984).

The amendment of the soil with a readily-labile source of carbon is supposed to ameliorate the removal of contaminants by stimulating microbial activity and enhancing anoxic conditions in the subsurface. According to Robertson's research (2010), wood-particle media such as woodchips and sawdust have been shown to produce constant long-term nitrogen removal (5 and 15 years) when used as a bioreactor. Due to the presence of active ion exchange sites such as cellulose, lignin and tannins, woodchips are also able to sorb cations (Shukla et al., 2002). Indeed, Ahmed et al. (2011) utilized this sorption capability for the development of a slow-release nitrogen fertilizer.

In the literature, there are several successful examples of carbonaceous solid application to reduce nitrogen concentrations in drinking water, groundwater, tile drainage effluents and stormwater (Volokita et al., 1996; Kim et al., 2003; Robertson et al., 2009; Dumont et al., 2014). Published researches report mainly three different woodchip configurations: the material has been implemented as "vertical walls" into shallow groundwater (Jaynes et al., 2008; Schipper and Vojvodic-Vukovic, 1998); as "beds" receiving wastewater, tile discharge (Schipper et al., 2010b; Robertson and Merkely, 2009) or "stream bed bioreactors" (Robertson and Merkely, 2009); and as "layers" of organic materials below septic tanks effluent (Schipper and McGill, 2008). Therefore, published studies did not deal with the incorporation of wood media directly into a vegetation filter irrigated with wastewater so far.

In general, the use of wood media has several advantages: it is commonly available at low cost, has a high carbon-nitrogen ratio, a high durability (Robertson et al., 2009) and it is easy to apply. Moreover in the context of a vegetation filter, this material can be supplied by the installation itself.

This research arises from a previous study developed in Carrión de los Céspedes (Seville, Spain) where a vegetation filter with a short-rotation poplar species was used to treat wastewater from an office building with a high nutrient load (de Miguel et al., 2014). To assess the ability of the soil-plant-microbe system to remove contaminants, the wastewater was applied directly on the soil surface after its passage through an Imhoff tank. Although high total nitrogen (N_T) removal percentages (73%) were obtained during infiltration through the soil, average concentration of N_T in the drainage water was still 42 mg L^{-1}. On this basis, leaching column experiments were carried out to explore if the addition of woodchips to the soil could be a feasible strategy to be integrated in the existing vegetation filter for improvement of removal of nitrogen and other wastewater contaminants. Specifically we aim to (i) evaluate if nitrogen and phosphorous removal is enhanced by the addition of a carbonaceous material to the soil; (ii) investigate impacts of using woodchips on chemical oxygen demand (COD); (iii) explore which is the best configuration between soil and woodchips for contaminant remediation.

2. Material and methods

2.1. Woodchips collection and preparation

Fresh poplar woodchips were obtained by means of a mechanical chipper from an existing stockpile located in Central Italy. After being dried, the wood particles were sent to Imdea Water laboratories (Spain). Before their use in the column experiments, the woodchips were passed through a 12.7 mm sieve, rinsed with tap water to eliminate wood dust and dried in the oven at 50 °C.

2.2. Soil sample collection and preparation

Soil samples were collected, down to 20 cm of depth, from the operating vegetation filter installed in Carrión de los Céspedes (Seville, Spain) (de Miguel et al., 2014). Sampling was performed in October 2014. Soil samples were air-dried, gently crushed and passed through a 2 mm sieve. pH and electrical conductivity (EC) were measured in a sediment–water suspension (soil–water ratio 1:2.5 and 1:5, respectively). Particle size distribution was determined following the method of Gee and Bauder (1986). Part of the air-dried, sieved sample was crushed for the determination of the sediment organic carbon fraction (f_{OC}) following the method of Nelson and Sommers (1982). Organic carbon content was determined by the Walkley–Black method, consisting in potassium dichromate-sulphuric acid oxidation (Nelson and Sommers, 1982). Cation exchange capacity (CEC) was determined by extraction with ammonium and sodium acetate solutions and the exchangeable bases by extraction with ammonium acetate. After soil extraction, exchangeable cation concentrations (Na^+, K^+, Mg^{2+}, Ca^{2+}) were analyzed by inductively coupled plasma mass spectrometry (ICP-MS). N_T soil contents were measured using the Kjeldahl method. NO_3-N soil contents were extracted following the method described by Griffin et al. (2011) and analyzed using a two-channel advanced compact ion chromatograph apparatus. P_T soil contents were extracted through acid digestion in microwave and measured using the ICP-MS. Soil properties are summarized in Table 1.

2.3. Synthesis of wastewater

Synthetic wastewater (SWW) mimicking real wastewater applied to the vegetation filter of Carrión de los Céspedes was produced dissolving the following reagents (purity > 95.0%) in tap water: NaCl (0.100 g L^{-1}), $MgSO_4$ (0.055 g L^{-1}), K_2HPO_4 (0.050 g L^{-1}), $(NH_4)_2CO_3$ (0.650 g L^{-1}), KCl (0.050 g L^{-1}), peptone (0.075 g L^{-1}) and meat extract (0.175 g L^{-1}). Once prepared, the SWW was purged with nitrogen gas (N_2) until dissolved oxygen concentration was below 1.5 mg L^{-1}. The compositions of the SWW and the original wastewater are shown in Table 2. The software PHREEQC-2 (Parkhurst and Appelo, 1999) was used to check the thermodynamic stability of the solution, confirming the absence of mineral precipitation. Periodic analyses of the SWW were also performed to exclude both mineral precipitation and microbial degradation. Results proved that the SWW could be stored at 4 °C during approximately two weeks without changes in chemical composition.