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Ecological Engineering 26 (2006) 293–303
ECOLOGICAL ENGINEERING
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Removal of phosphates by pilot vertical-flow constructed wetlands using a mixture of sand and dolomite as substrate

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Received 28 June 2005; received in revised form 20 October 2005; accepted 28 October 2005

Abstract

This study evaluates the performance of a mixture of river sand and dolomite (10:1, w/w) used as substrate in vertical-flow constructed wetlands in removal of phosphates. Two duplicate pilot-scale artificial wetlands (total 4 units) were set up outdoors, planted with *Phragmites australis* and fed with a synthetic sewage solution, corresponding to medium strength municipal wastewater. The wetlands were fed with two batch (intermittent) operational modes and their effluent was monitored for the presence of soluble phosphates over a period of 3 months. Laboratory (batch) incubation experiments were also carried out separately to ascertain the phosphate adsorption capacity of the two materials (i.e. sand and dolomite). The wetlands were capable to remove more than 45% of initially applied phosphates. Phosphorus accumulation in the wetlands body at the end of the operation period was in the range of 6.5–18%, as compared with the unused media. The Ca Mehlich-III extractable content was also increased, indicating that the removal of phosphates would be mainly attributed to the sorption of orthophosphate ions onto calcium carbonates and/or to the precipitation of orthophosphate ions with calcium ions as the respective insoluble calcium phosphates.

Keywords: Constructed wetlands; Vertical flow; Dolomite; Sand; Phosphorus removal; Sorption

1. Introduction

Vertical-flow constructed wetlands (or soil filters, or reed bed systems) have become a common treatment selection of urban wastewaters during the last decade. They are attractive in specific cases, where other natural systems cannot be easily applied, due to the relatively small surface requirement and their high purification efficiency in terms of organic matter and ammonia, although their efficiency is smaller in phosphorus removal; Fisher (1998) reported a 20% P removal by gravel wetland. Vertical-flow systems are intermittently flooded and drained, allowing air to refill the soil pores within the bed. The dimensioning of the vertical-flow constructed wetlands varies widely between 1 and 2 m^2/p.e. and up to 5 m^2/p.e. (Cooper et al., 1997).

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doi:10.1016/j.ecoleng.2005.10.009

Phosphorus is the main factor involved in eutrophication of surface (inland) waters, hence its effective removal from wastewaters has been of growing interest in constructed wetland applications. Phosphorus is present in urban sewage at levels between 6 and 10 mg l^{-1}, while an even lower than 10 mg l^{-1} concentration in inland waters may stimulate algal growth (Horan, 1990). The respective effluent limits for phosphorus in wastewater treatment plants of the European Union, according to the directive 91/271/EE, are 1–2 mg l^{-1} of total phosphorus, depending on the sensitiveness of the receiving water body. Considering also that removal efficiency of conventional biological wastewater treatment plants is often small due to mechanical, financial, and limited personnel reasons, alternative treatment methods should be applied to tackle this problem (Tsagarakis et al., 2003).

Several studies have reported on the potential use of constructed wetlands in the removal of phosphates from wastewaters (Sakadevan and Bavor, 1998; Molle et al., 2003). Phosphorus removal in wetlands may take place due to plant uptake (Greenway and Wooley, 1999), accretions of wetland soils (Kaldec et al., 1997), microbial immobilization (Reddy and D'Angelo, 1997), retention by the substrate and precipitation in the water column (Gray et al., 2000). Among these factors, the substrate may play the greatest role and could be the factor most amenable to control. Consequently, it is important to select those substrates presenting the highest phosphate adsorption capacity, which depends mainly on the specific physico–chemical properties of these materials (Zhu et al., 1997; Drizo et al., 1999; Brooks et al., 2000).

Various media in addition to the commonly used sand and gravel have been utilized in order to improve the removal mechanisms of precipitation and adsorption, including: limestone, shale, slag, wollastonite, iron rich gravel, zeolite, calcite and other artificial materials (Zhu et al., 1997; Drizo et al., 1999; Brix et al., 2001). Zeolite and pelleted clay, either alone or in combination with soils, alum, calcite and dolomite, was found to improve the phosphate retention capacity of constructed wetlands (Ann et al., 2000). It was reported that shale-based wetlands had 98–100% P removal capacity (Mann, 1997). Such substrates include minerals with reactive iron or aluminium hydroxide or oxide groups on their surfaces, or calcareous materials, which can promote calcium phosphate precipitation (Zhu et al., 1997). Apart from Fe, Al and Ca minerals, the phosphorus adsorption capacity of the wetland is controlled by the specific substrate pH value, and the respective adsorptive surface area (Stumm and Morgan, 1981). Larger surface area, which is characteristic of fine-grained materials, could increase P adsorption (and removal). However, such materials present usually low hydraulic conductivity, which leads to clogging and insufficient contact between wastewater and substrate within the wetland. Moreover, the performance of vertical-flow wetlands in removal of phosphates depends also on the applied operational or design parameters, such as the hydraulic load, the P load and the frequency of (batch) loads.

Therefore, the materials selected as wetland substrates, should be sufficiently permeable to prevent clogging and should also be relatively inexpensive and locally available, in order to reduce the costs of facility construction wetlands creation. Moreover, the appropriate combination of design and operational parameters should be applied (U.S. EPA, 1988).

The present study examines the use of a 10:1 (w/w) mixture of river sand and dolomite as a potential constructed wetland substrate, which meets the aforementioned criteria. The selection of the substrate was such to increase P retention capacity (with the addition of a calcareous material), without inducing high pH values, which would be incompatible with sensitive water bodies used as final effluent receivers discharging, such as rivers, as well as avoiding problems with the growth of the commonly applied reed *Phragmites australis.*

The objectives of this study were two-fold: (i) to determine the major physico–chemical properties of sand and dolomite, which influence the effectiveness of substrate of the removal of phosphates, including the maximum adsorption capacity of these materials and (ii) to compare the phosphate removal performance of four outdoor pilot-scale vertical-flow constructed wetland systems, filled with a mixture of river sand and dolomite at a rate of 10:1 (w/w) and planted with *P. australis*. The four systems were subjected to two different operational conditions (two replicate wetlands per treatment) and the presented results concern the 3 months of operation, which followed the construction and the establishment of the wetlands.