Ecological Engineering 35 (2009) 1693–1701

Contents lists available at ScienceDirect

Ecological Engineering

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

Phosphorus reduction from agricultural runoff in a pilot-scale surface-flow constructed wetland

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ARTICLE INFO

Article history:
Received 26 June 2008
Received in revised form 23 April 2009
Accepted 19 May 2009

Keywords:
Constructed wetland
Phosphorus
Agricultural runoff
Non-point pollution
Soil
Surface flow
Quebec
ORP
DO

ABSTRACT

Excess P in surface waters in Quebec is the primary cause of water quality deterioration and the majority of it is coming from agricultural land as non-point source pollution. The objective of this study was to compare how two substrates, a sandy clay loam and a sand soil, influenced P retention in a surface-flow constructed wetland (CW). A secondary objective was to determine if the hydraulic residence time of the wetland differed between soil types. Measurements were taken at a pilot-scale CW site between July 5 and October 1, 2007. Three cylindrical tank replicates filled with sandy clay loam soil, and three with a sandy soil were planted with cattails (*Typha latifolia* L.) and reed canary grass (*Phalaris arundinaceae* L.). The tanks were flooded continuously with an artificial agricultural runoff solution containing 0.3 mg L^{-1} dissolved reactive P. The six treatment tanks retained 0.9–1.6 g P m^{-2}, which corresponded to an average removal efficiency of 41%; there was no significant difference in the P retention by the two soil types. A bromide tracer test revealed a mean hydraulic retention time of 2.2 days for all tanks; however, the active volume of the sand tanks was greater. This investigation suggests that a sandy soil may be less prone to reducing conditions in a surface-flow CW and therefore maintain its role as a P sink for longer than the sandy clay loam.

1. Introduction

Nutrient overloading of freshwater bodies in North America has had a significant impact on their degradation. Diffuse, or non-point source (NPS) pollution, especially from agricultural land, has been deemed the primary cause of these excess nutrients, mainly phosphorus and nitrogen, in fresh water sources (Kellogg and Maizel, 1994). As industrial farms continue to intensify production, soil P levels are increasing beyond their absorption capacity and the excess is being lost in surface runoff and subsurface drainage water. Phosphorus is targeted for reduction because it is often rate limiting to the growth of freshwater algae (Braskerud, 2002). The high soil P is the result of both manure spreading and mineral P fertilizer application; in the case of meat producers, they often have more manure than land available for spreading leading to over-application, and in the case of crop producers, over-application of mineral fertilizer is common as maximum crop yield is the goal (Berka et al., 2001).

Generally, CWs treating direct on-farm waste such as manure pile runoff or milk house wash are dealing with concentrated waste streams. In contrast, non-point source agricultural runoff is characterized by large volumes of water with lower concentrations coming from agricultural land, either from the surface or subsurface drains. In Quebec, the increasing number of blue-green algae outbreaks in lakes and streams has been attributed to excess P in the watersheds with upwards of 70% estimated to be coming from agricultural non-point sources (Stämpfli, 2006). Moss (1995) stated that "as a rule of thumb, if the N:P ratio by weight is much greater than 10, the lake will be phosphorus-limited. If it is less than 10, the lake will be likely to be nitrogen-limited." In many natural ecological systems, P is the growth-limiting nutrient as N is naturally more abundant. Controlling the source of the nutrients is the most cost-effective long term management option (Berka et al., 2001) and therefore best management practices at the farm scale to reduce, and ideally prevent nutrient loss from the farm are being studied and implemented.

CWs are interesting best management tools as the concept can be implemented in many situations and built with locally available materials (Casey and Klaine, 2001; Aye et al., 2006). In designing a CW as a best management tool, it is important to understand not only the nutrient removal mechanisms which occur naturally in a wetland, but how these mechanisms are affected by the available structural components and the local environment. This study explored how P removal was impacted by two different soil sub-

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doi:10.1016/j.ecoleng.2009.05.005

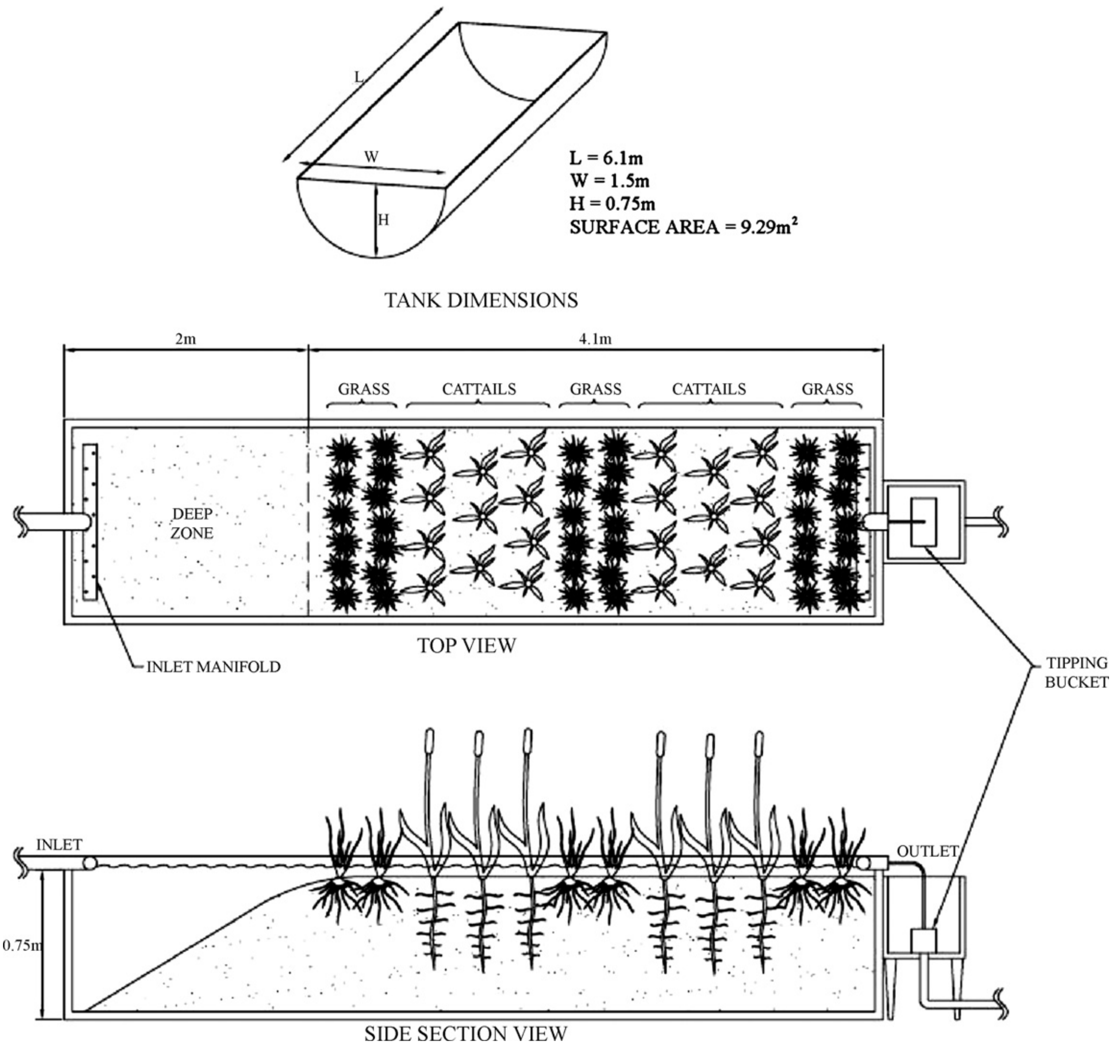

Fig. 1. Side and top view of the six soil treatment tanks.

strates in order to help optimize the design of the CW within the framework of the target runoff.

The physicochemical properties of the wetland system dictate which P removal mechanisms will dominate, should P removal occur (Kadlec, 2005). Wetland nutrient cycling is dependent on the process dynamics present within the system such as oxidation–reduction potential (ORP), dissolved oxygen (DO), pH and temperature (House et al., 1995; Sharpley, 1995). Under aerobic conditions, P readily forms insoluble complexes with hydrous oxides of aluminium, iron and calcium (Sakadevan and Bavor, 1998; Kadlec and Knight, 1996). Dissolved inorganic P ($H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-}) is also readily taken up by plants and microbes (immobilized) and converted into organic P forms. The litter from living organisms can release organic P into the system which can be converted back into inorganic dissolved P (mineralized), remain immobilized through incorporation into the sediments or exit the wetland as dissolved organic P (DOP). The ability of soil to bind and retain P through adsorption and precipitation is greatly influenced by its Al and Fe concentration and its quantity of exchangeable cations (CEC).

The goal of this research was to determine if the soil substrate had an impact on a surface-flow CW's capacity to reduce dissolved P from agricultural runoff. The first objective was to determine if there was a difference between two soil types common to Southern Quebec; a sandy clay loam soil and a sand soil, in their ability to reduce dissolved P from a simulated agricultural runoff solution. The second objective was to determine experimentally what the mean hydraulic retention time was for the CW treatment tanks with the different soil types and how this impacted P removal efficiencies. It was expected that the sandy clay loam would outperform the sandy soil in P removal for three reasons; it would (1) allow for greater P binding directly to the soil particles because of a larger pool of Al^{3+} and Fe^{3+}, (2) have a longer hydraulic residence time due to the higher clay content and (3) due to its higher nutrient content promote and sustain and larger vegetation cover thus increasing the amount of P uptake by plants.

2. Methodology

2.1. Site description

Field measurements were made at a pilot-scale CW research site located 3 km north of McGill University's Macdonald Campus in Ste-Anne-de-Bellevue, Quebec, Canada. The site became operational in the summer of 2006 when the plants and instrumentation were established. In October of 2006 the tanks were drained until this