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Medium clogging and the dynamics of organic matter accumulation in constructed wetlands

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ABSTRACT

The side-to-side comparative studies were conducted on the unplanted plot and planted plots with two macrophyte species in a Small-Scale Experimental Constructed Wetland System operated under high hydraulic loading condition over a period of one year until the wetland medium was completely clogged. Accumulation dynamics of each organic matter component, and its correlation with the medium permeability coefficient were studied during the clogging process. Our results show that growing plants delayed the medium clogging process in the wetland, and for this purpose *Canna indica* is more effective than *Cyperus alternifolius*. The percentage of each component of organic matter was affected by the type of plants. *C. indica* promoted more strongly the accumulation of the active organic matter whereas *C. alternifolius* was more effective in enhancing production of fulvic acid. Both plant species led to lower humin contents in the wetland medium. Among all the components of organic matter, labile organic matter and fulvic acid were the leading factors causing wetland clogging, with the former playing the most prominent role in the process.

1. Introduction

Constructed wetlands are widely used as an efficient alternative means of wastewater treatment over the world (Paing and Voisin, 2005). Compared to conventional wastewater treatment technologies, constructed wetlands have been proved to be advantageous in the low investment and energy consumption, easy management and avoidance of secondary pollution (Machate et al., 1997; Rizo et al., 1999; Knight et al., 2000). However, limited by pollution tolerance and pollutant removal ability, subsurface clogging has been one of the worst operational problems for the constructed wetlands (Yu et al., 2006). Once clogged, the medium surface is submerged in brackish water, and over time production of foul odors and population growth of mosquitoes and other insects will result in environmental aggravation. The anaerobic environment in a degraded wetland will lead to further declining of the contaminant-purification capacity. Therefore, wetland clogging mechanisms have been the focus of study among environmental scientists.

Wetland clogging is a very complex but poorly understood process. Accumulation of organic matter was described as the major contributing factor to clogging (Tanner et al., 1998b; US EPA, 1993). When the content of organic matter reaches 5% and above, a black gelatinous bio-film will form on the substrate to clog the wetland (Xiao and Cui, 2001; Yan et al., 2008). In order to validate the role of organic matter in wetland clogging, it is necessary to determine the accumulation and the biodegradability of each component contained in those materials (Knowles et al., 2011). Tanner et al. (1998a) studied a horizontal-flow wetland used to treat dairy wastewater, and found that 80% of the organic matter is unstable and readily degradable. However, Nguyen (2000) showed that the porous media of the wetland were clogged by organic matter in which over 90% are recalcitrant organic compounds, and 63–96% is in the forms of humic acids, fulvic acids and humins. Results from those two studies, in spite of the discrepancies, are only useful when using horizontal-flow wetland for the treatment of dairy wastewater.

Large scale vertical-flow constructed wetland (VFCW) was used in Shenzhen and Wuhan cities, for wastewater treatment and the clogging mechanisms have not been well studied. In this paper, the analytical methods of soil organic matters were used to determine the contents of labile organic matter (LOM), humic acid (HA), fulvic acid (FA) and humin (HM) in the substrate over the clogging process of a small scale VFCW plots. The dynamics of each organic matter component and the correlation between organic matter and substrate permeability coefficient were analyzed. We also compared the effectiveness of *Canna indica* and *Cyperus alternifolius* in preventing wetland clogging and their contribution to the

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Table 1
Quality parameters of the influent in the small scale plots wetland system.

Parameters	pH	ORP (mV)	DO (mg/L)	COD_{Cr}(mg/L)	TN (mg/L)	TP (mg/L)	TSS (mg/L)
Influent water quality	7.90 ± 0.41	−49.0 ± 19.29	4.17 ± 2.37	112.16 ± 25.64	27.52 ± 7.33	2.49 ± 1.02	27.75 ± 7

accumulation of different component of organic matter. Major organic matter components contributing to wetland clogging were identified in this system.

2. Materials and methods

2.1. The small scale plots wetland system

Three vertical flow constructed wetland plots were built in Shenzhen, China (Fig. 1). Each plot is in the same size, 125 cm in length, 125 cm in width and 100 cm in height. *C. indica* and *C. alternifolius* were planted in the plot A and B, respectively, and the unplanted plot C was used as control. *C. indica* and *C. alternifolius* were planted in the holes at a distance of 0.4 m by 0.4 m, and there were three shoots in each hole. The three vertical flow constructed wetland (VFCW) plots were established with three-layer filters: 0.2 m layer of larger gravels of 8–16 mm in diameters in the bottom followed by a 0.2 m layer of smaller gravels of 4–8 mm in the middle and a 0.5 m layer of fine gravels of 0–4 mm at the top. The proportion of the filler materials was chosen following the instructions in the current wetland filler configuration in Shenzhen, China (Wang, 2008).

2.2. Experimental influent

The small scale plots (SSPs) were fed with domestic wastewater from Tangtou River in Shenzhen, China. The suspended solids of influents were removed as much as possible by using the inlet screen of wetland and the sieve in the pump as well as the pipeline networks. The quality of the influent is described in Table 1. System began to run in December 2010, water was let flowing into the wetland system twice daily from 8:30 to 11:00 am from 2:30 to 5:00 pm. The hydraulic loading was set at 1000 mm/d (controlled by a LZS-32 model plastic float flow meter) before the system steady. Start from January 1 2011 the hydraulic loading increased to 2000 mm/d until the wetland was clogged completely.

2.3. Sample collection and analysis

2.3.1. Matrix sample collection

Hua et al. (2010) found that 80–90% solid particles are contained within the first 0–6 cm layer of the wetland, and those materials become more compact with depth of the system. A study by Niu et al. (2002) indicated that the accumulations of organic matter in the vertical flow wetland substrate, 60% of organic matters are deposited within the 0–10 cm layer. So the matrix upper 0–10 cm was used for this experiment. Three substratum samples of each plot were taken from three random spots with self-made sampler. Areas around influent pipes were avoided to reduce variation in permeability coefficient introduced by hydraulic scouring of the substrate.

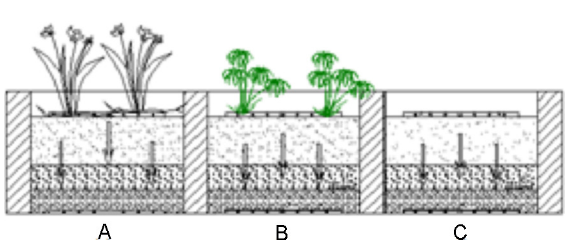

Fig. 1. Section view of small scale plots.

2.3.2. Permeability coefficient measurements

The measurements were made by the Constant Head Permeation Experimental Method in soil test procedures SL237-1999 (The Ministry of Water Resources of The People's Republic of China, 1999), using a TST-70 model constant head infiltration meter.

2.3.3. Assay methods for components of organic fractions

Soil labile organic matter (LOM), and humus species (humic acid-HA, fulvic acid-FA and humin-HM) were analyzed by the methods in Table 2. The total organic matter (SOM) was the sum of LOM, HA, FA, and HM.

2.3.4. Data analysis

The statistical analyses of the data were conducted by using MS EXCEL 2010, Origin 8.5 and SPSS 13.0.

3. Results and analysis

3.1. Changes of the substrate permeability coefficient during wetland clogging

Wetland clogging is characterized by the rapid decline in the medium permeability, hydraulic conductivity, and surface water ponding, resulting in the malfunction of system and even loss of water purification. The changes of permeability coefficient over time in each unit were showed in Fig. 2. It can be found that the infiltration rate was nearby 6.7×10^{-3} cm/s when the systems clogged. So defined the key permeability coefficient $K_s = 6.7 \times 10^{-3}$ cm/s to quantify the occurrence of clogging in the system. It is worth noting that the filler arrangement of small scale plots were configured in accord to the Current Wetland Standard in Shenzhen, therefore this data can also be used as a reference point for wetland management across the city. In this study, as can be seen from Fig. 2, clogging of unit C occurred much sooner than A and B, and B was clogged before unit A. It is suggested that the macrophytes can postpone the wetland clogging to some extent, depending on the type of plants. There were two reasons for this phenomenon. First, plant rhizomes and roots can penetrate and loosen substrate matrix, thereby improving the porosity to a certain extent. Studies have shown that plants can actually improve the porous ratio of substrate by 3–44% (Wang et al., 2008). Secondly, plant rhizomes and roots provide an aerobic environment which accelerates microbial degradation of organic matters, and this will slow down the clogging progression of wetland.

Table 2
Assay methods of organic matter.

Organic fractions	Assay methods	References
Humus fractions $W_{HA}/W_{FA}/W_{HM}$	Sodium pyrophosphate – potassium dichromate extraction	Nanjing Institute of Soil, Chinese Academy of Sciences (1978)
Labile organic matter W_{LOM}	$K_2Cr_2O_7$–H_2SO_4digestion method	Yuan (1963)