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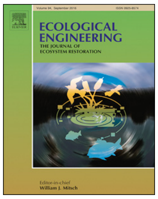

Performance of ornamental plants in monoculture and polyculture horizontal subsurface flow constructed wetlands for treating wastewater

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ABSTRACT

The aim of this study was to evaluate the effect of two ornamental plants in monoculture and polyculture horizontal subsurface flow (HSSF) constructed wetlands for treating wastewater. Two pilot-scale HSSF systems each with a surface area of 4.5 m^2 were operated over two years (2015 and 2016); a) one was planted with a mixture of *Cyperus papyrus* and *Zantedeschia aethiopica* (HSSF-Cyp/Zant), and b) the other was planted only with *Cyperus papyrus* (HSSF-Cyp). To compare the performance between monoculture and polyculture systems, *in situ* parameters and organic matter (chemical oxygen demand (COD) and biological oxygen demand (BOD_5)), total suspended solids (TSS), nutrients (total nitrogen (TN) and total phosphorus (TP)) and pathogens (fecal coliform (FC) and total coliform (TC)) removal efficiencies were evaluated. Moreover, growth characteristics, biomass production and nutrients uptake of different plants used in HSSF systems were also compared. The removal efficiencies of organic matter, suspended solids, nutrients and pathogens during the operational years were above 60%, 90%, 10% and 1.8 Log most probable number (MPN)/100 mL, respectively, without significant differences between HSSF-Cyp/Zant and HSSF-Cyp. The biomass production and the density of both HSSF systems fluctuated between 19.7 and 21.5 kg dry weight (DW)/m^2 and 454–684 individuals/m^2. Regarding the nutrient content of different plants used, *Zantedeschia aethiopica*, which was planted in the polyculture system, had the highest TN and TP content in all plants tissues (59.6 g N/kg·DW and 8.28 g P/kg·DW, respectively). However, TN and TP mass balances determined that the effect of monoculture and polyculture systems was not significant. Despite these results, polyculture CWs represent a good alternative of treatment system because they provide social benefits to the community such the improving of the system landscape and a better habitat quality. Moreover, some authors reported that polyculture system enhance the resistance to environmental stress and disease and the system landscape.

1. Introduction

Constructed wetlands (CWs) are engineered systems designed for treating industrial and domestic wastewater. They are considered an attractive solution to use in rural areas with a population of up to 2000 equivalent habitants (Carballeira et al., 2016; Vymazal, 2011). The advantages of this technology are their simplicity, good performance and maintenance cost between 13 and 101 USD/hab (Vera et al., 2011).

Plants are considered to be an essential component of CWs. Their most important roles are related to their physical effects, the uptake of nutrients, the release of oxygen to the rhizosphere and the microorganism hosting (Brix, 1997; Shelef et al., 2013). *Phragmites* spp., *Typha* spp. and *Schoenoplectus* spp. are the most frequent plant species used in these systems (Vymazal, 2011). However, it is known that the use of ornamental plants in CWs is an attractive alternative for small communities due to their capacity to improve the treatment system landscape and their commercial values through the production of flowers and fibers (Zurita et al., 2009). In fact, these systems achieve removal efficiencies of total suspended solids (TSS), chemical oxygen demand (COD) and biological oxygen demand (BOD_5) of over 60% (Burgos et al., 2017; Calheiros et al., 2015; Zurita et al., 2011). In addition, ammoniacal nitrogen (NH_4^+-N) and total phosphorus (TP) removal efficiencies have been documented in the ranges of 48–55% and 24–50%, respectively (Belmont and Metcalfe, 2003; Merino-Solís et al., 2015). In the cases of fecal coliform (FC) and total coliform (TC), some studies have reported removal efficiencies above 95% (Abou-Elela and Hellal, 2012). These results suggest that it is possible to use ornamental plants in CWs without reducing the efficiency of treatment system.

One aspect that has been controversial is the effect of monoculture and polyculture in CWs. A comparative study between a monoculture system planted with *Canna indica* and a polyculture system planted with *Canna indica* and *Lythrum salicaria* showed that removal efficiencies of

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COD were 1.2 times higher in the polyculture system (Zhou et al., 2017). This difference was attributed to temporal and spatial compensation, root distribution and nutrient preferences that predominated in polyculture configurations (Karathanasis et al., 2003). However, Liang et al. (2011) observed that the monoculture wetland had significantly higher COD and NH_4^+-N removal rates than the polyculture wetland during the first year of operation ($p < 0.05$). Another comparative study reported that monoculture and polyculture wetlands planted with *Canna indica* and *Schoenoplectus validus* achieved NH_4^+-N and phosphate (PO_4^{-3}-P) removal efficiencies above 90% and 70%, respectively, without a significant difference ($p > 0.05$) (Zhang et al., 2007). Regarding the effect of these systems on plant growth characteristics, Liang et al. (2011) also found that a polyculture wetland had a density between 85.6 and 123.8 individuals/m^2, whereas the monoculture presented a density between 56 and 86.3 individuals/m^2. Nonetheless, during the first year, the monoculture wetland had a larger biomass (2.0 kg of dry weight (DW)/m^2) compared to the polyculture system (1.7 kg·DW/m^2). In this same study, this behavior changed during the latter three years, where biomass production was 1.2–1.7 times higher in the polyculture system. These results indicate that the differences between monoculture and polyculture wetlands are still unclear. To improve the performance of polyculture in constructed wetlands, some authors suggest a good plant selection for avoiding species competition that may affect nutrient removal and vegetation stability in CWs (Zhang et al., 2007).

Taking the above into account, the aim of this study was to compare the effect of two ornamental plants, *Zantedeschia aethiopica* and *Cyperus papyrus*, in monoculture and polyculture horizontal subsurface flow (HSSF) CWs for treating wastewater.

2. Materials and methods

2.1. Design of HSSF systems

The wetland system consists in a HSSF pilot plant located in Hualqui (36°59′26.93″ south latitude and 72°56′47.23″ west longitude), Biobío Region, Chile. The influent used corresponded to the wastewater from a rural community of 20,000 inhabitants. The wastewater was subjected to a pre-treatment and then to a primary treatment, which were described by López et al. (2015) and Sepúlveda-Mardones et al. (2017).

Table 1
Operational conditions and design parameters of HSSF-Cyp/Zant and HSSF-Cyp.

Operational parameters[a]						
Year	Season	OLR (gBOD$_5$/m^2·d)	HLR (mm/d)	HRT (d)	ET (mm/d)	P (mm/d)
2015	F/W	5.7 ± 1.8	26.7 ± 2.0	6	1.5	2.3
	S/Sm	4.1 ± 0.5	28.9 ± 1.5	6	3.5	1.3
2016	F/W	5.2 ± 2.0	24.4 ± 2.3	6	1.5	3.5
	S/Sm	5.1 ± 2.3	22.2 ± 3.2	5	3.5	0.6

[a] Operational and design parameters are the same for both constructed wetlands. OLR: organic loading rate; HLR: hydraulic loading rate; HRT: hydraulic retention time; ET: evapotranspiration; P: precipitation; F/W: Fall/Winter season and S/Sm: Spring/Summer season.

Fig. 1a) shows a schematic diagram of the system. After the distribution tank, the influent was conducted to two parallel HSSF CWs. One of them was planted with *Cyperus papyrus* (HSSF-Cyp), and the other was planted with a mixture of *Cyperus papyrus* (11 plantlets) and *Zantedeschia aethiopica* (7 plantlets) (HSSF-Cyp/Zant). These two ornamental plant species are commonly used in CWs applications (Vymazal, 2011). In addition, Fig. 1b) explained the cross section of each pilot-scale HSSF, which was divided into three zones separated by three sampling tubes: Zone A (the inlet zone), 0.65 m from the inlet; Zone B (the middle zone), 1.4 m from the inlet; and Zone C (the outlet zone), 2.25 m from the inlet. The surface area of each zone was 1.5 m^2 (López et al., 2015).

Table 1 summarizes the operational conditions and design parameters of HSSF systems. Each HSSF constructed wetland had an area of 4.5 m^2, a water level of 0.4 m, an average depth of 0.57 m and a theoretical volume of 1.28 m^3. The support medium used was gravel with a size of 19–25 mm and a porosity of 0.6% (Sepúlveda-Mardones et al., 2017). The gravel used in this study has the same characteristics described by Andrés et al. (2018). This support medium was composed by quartz (SiO_2), muscovite mica ($KAl_2(Si_3Al)O_{10}(OH)^2$) and feldspar ($(K,Na,Ca,Ba,NH_4)(Si,Al)_4O_8$). During the operation, the organic loading rates (OLRs) were in the range of 4.1–5.7 gBOD$_5$/m^2 d during 2015–2016. For the hydraulic loading rates (HLRs) and the hydraulic retention times (HRTs), these values varied between 22.2 and 28.9 mm/d and 5–6 d, respectively. The evapotranspiration (ET) presented

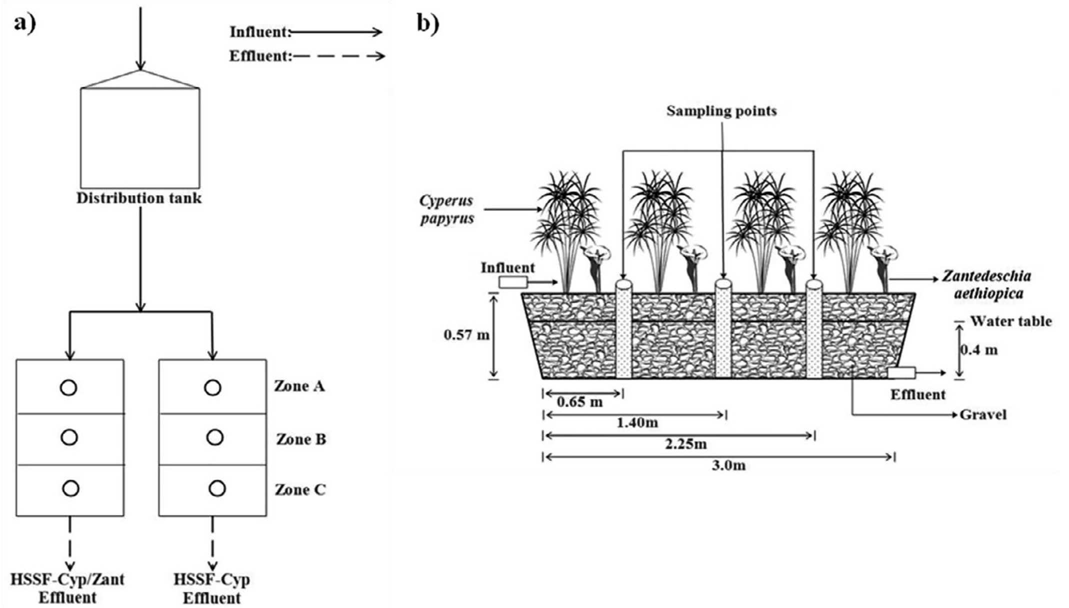

Fig. 1. a) Schematic diagram of pilot-scale wastewater treatment plant using horizontal subsurface flow constructed wetlands (HSSFs). b) Cross section of each pilot-scale HSSF showing dimensions and *in situ* measurement points (cylindrical tubes).