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Treatment of domestic wastewater and production of commercial flowers in vertical and horizontal subsurface-flow constructed wetlands

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ABSTRACT

In developing countries, the use of non-conventional plant species as emergent plants in constructed wetlands may add economic benefits besides treating wastewater. In this work, the use of four commercial-valuable ornamental species (*Zantedeschia aethiopica*, *Strelitzia reginae*, *Anturium andreanum* and *Agapanthus africanus*) was investigated in two types of subsurface wetlands for domestic wastewater treatment. Several water quality parameters were evaluated at the inlet and outlets of a pilot-scale system. Physical measurements were used to evaluate and compare the development of the ornamental plants under two patterns of flow in subsurface wetlands.

The results for pollutant removal were significantly higher in the vertical subsurface-flow constructed wetlands (VFCW) for most pollutants. The average removals were more than 80% for BOD and COD; 50.6% for Org-N; 72.2% for NH_4^+, 50% for Total-P and 96.9% for TC. Only two pollutants were removed in statistically higher percentages in the horizontal subsurface-flow constructed wetlands (HFCW) (NO_3^-, 47.7% and TSS, 82%). The pollutant removal efficiencies were similar to the results obtained in many studies with conventional macrophytes. Most ornamental plants survived the 12-month period of experimentation and their development depended on the type of constructed wetland they were planted. *Z. aethiopica* looked healthier and produced around 60 flowers in the HFCW. The other three species developed better in the VFCW, although *A. andreanum* died during the winter. *S. reginae* produced healthier flowers (and more) and bigger leaves and *A. Agapanthus* produced more leaves and more lasting flowers. This suggests that it is possible to produce commercial flowers in constructed wetlands without reducing the efficiency of the treatment system.

1. Introduction

The use of constructed wetlands with both horizontal and vertical flow is increasing around the world for domestic wastewater treatment (Vymazal, 2002, 2005a; Senzia et al., 2003; Liu et al., 2005). In the USA, as well as in Europe, most systems operate with horizontal flow (Vymazal, 2005a). In the USA there are around 8000 facilities while in Germany the estimation is approximately 50,000 (Vymazal, 2005a). The HFCW can provide a reliable secondary level of treatment with regard to biochemical oxygen demand (BOD) and total suspended solids (TSS) but frequently are less effective for nitrogen removal; unless a longer hydraulic retention time and enough oxygenation are provided (Liu et al., 2005). On the other hand, VFCW are becoming more popular (Vymazal, 2005a; Molle et al., 2006) and currently they are subject to intensive research, mainly in Europe, in order to optimize their basic design parameters (Wallace, 2001; Korkusuz et al., 2004; Brix and Arias, 2005). It is well documented that this type of wetland is very effective not only for the removal of BOD and TSS but also for nitrification even at a high loading rate in a cold climate (Arias et al., 2005; Cooper, 2005; Prochaska et al., 2007) because they are intermittently flooded and drained, allowing air to refill the substrate pores within the bed (Prochaska and Zouboulis, 2006) and improving, in this way, the oxygen transfer from the atmosphere to the system.

Constructed wetlands are effective treatment systems that can be very useful in developing countries since they are simple technology and involve low operational costs. Most of the time, the wetlands can be constructed with local materials which lowers the construction cost significantly. Furthermore, these treatment systems are good at removing not only patogenics and nutrients but also toxic metals and organic pollutants (Belmont et al., 2006).

In developing countries the use of constructed wetlands is certainly lower in comparison to their use in Europe or the United

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States, despite the enormous potential and the great necessity of these countries to implement low-cost treatment systems. The warmer climate and the richness of biodiversity in most developing countries allow the use of non-conventional species, such as commercial-valuable ornamental plants, as emergent plants in constructed wetlands. These beautiful plants, besides improving the treatment system landscape, can provide economic benefits to the community through the production of flowers (Belmont et al., 2004; Zurita et al., 2006, 2008). In this work, four ornamental species in pilot-scale cells with different flow patterns were evaluated. The aim was to evaluate and compare the efficiency of the two types of subsurface wetlands for pollutant removal, as well as to evaluate and compare the development of ornamental species under different flow patterns in order to investigate the best flow regime for the development of each species.

2. Materials and methods

2.1. Description of the treatment wetland

This study was carried out in Ocotlán, Jalisco, Mexico, where the climate is classified as warm and wet with rainfall in summer (AC_W). The pilot-scale treatment system consisted of an 1100-l feeding tank used to store prescreened wastewater from the inlet of the Ocotlán's wastewater treatment plant. This wastewater was fed into a pair of HFCW measuring $3.6\,m \times 0.9\,m \times 0.3\,m$ ($L \times W \times H$) and into a pair of VFCWs measuring $1.8\,m \times 1.8\,m \times 0.7\,m$ ($L \times W \times H$) (Fig. 1); each wetland had a planted surface of $3.24\,m^2$. In the HFCW, the domestic wastewater was fed continuously at a rate of 128 l/d which corresponds to a hydraulic retention time of 4 days. In the VFCW, the domestic wastewater was fed intermittently by means of an automatic siphon, discharging 16 l every 3 h directly over the non-stratified substrate surface. As a result, the system operated by cyclic flooding and draining.

Both types of wetlands were filled with tezontle gravel, a volcanic red-orange extrusive rock. The use of this substrate is innovative because this material is not a typical substrate in treatment wetlands and its high porosity and richness in iron make it a good substrate for nutrient removal (Zurita et al., 2006). Furthermore, this material is abundant in this part of Mexico and therefore inexpensive, which it is important for this study since we are studying the feasibility of building low-cost treatment systems for developing countries. The average diameter of the rocks was 1.2 cm and its porosity was 0.53.

One HFCW and one VFCW were planted with just one species: 30 healthy plants of *Zantedeschia aethiopica* were distributed uniformly on the wetland surface. The other two wetlands were planted with three species: 6 plants of *Strelitzia reginae*, 6 plants of *Anthurium andreanum* and 3 plants of *Agapanthus africanus*, distributed aleatorily and uniformly on the wetland surface. This design allowed us to compare the performance of three ornamental species that have not been studied before with *Z. aethiopica* that has been evaluated previously in horizontal treatment wetlands (Belmont and Metcalfe, 2003; Belmont et al., 2004). The pilot-scale treatment wetland was exposed to the environmental conditions but protected from direct sunlight by shade screens.

2.2. Measurement of water quality parameters

The treatment system began to operate at the beginning of March 2006 and, the system was allowed to stabilize for three months. After this stabilization period, a monitoring of the wetland began and continued for 9 months for most parameters. The samples were taken weekly at five points in the system: at the input of the system and at the output of each wetland (Fig. 1). Chemical and biological water quality parameters were measured as described in the Standard Methods for the examination of Water and Wastewater (APHA, 1998). A potentiometer ORION model 410-A plus was used to measure pH.

2.3. Ambient temperature, humidity and plant growth measurements

Two parameters that strongly influence on plant growth and development, air temperature and humidity, were measured from September 2006 to February 2007. A HANNA thermohygrometer, model HI-8564, was used to measure both parameters twice a day; in the morning (from 8:00 to 11:00 h) and in the afternoon (from 4:00 p.m. to 7:00 p.m.).

The physical measurements were carried out in order to compare the final size of the same ornamental species under different flow patterns. All the plants from each cell were measured when they were well established in the system, in other words, after 7, 9 and 12 months of the pilot-scale system operation. The number of leaves produced, the number of shoots, the stem height, the stem thickness and the leaf size on each plant were measured. The number of flowers produced was quantified in the wetlands planted with *Z. aethiopica*, whereas, the number of plants which flowered

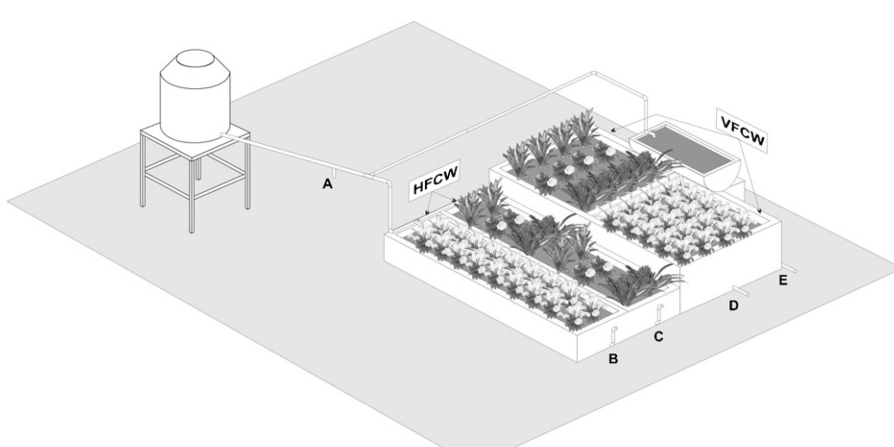

Fig. 1. Piloto-scale subsurface-flow constructed wetlands. VFCW, vertical subsurface-flow constructed wetland; HFCW, horizontal subsurface-flow constructed wetland; A, B, C, D, E, sample points.