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Palm tree mulch as substrate for primary treatment wetlands processing high strength urban wastewater

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ABSTRACT

The life span of subsurface flow treatment wetlands is determined by the clogging of the substrate. Thus, the influent should undergo primary treatment to reduce loadings of suspended solids and dissolved organic matter. An-organic based substrate should be less prone to clogging because of its remarkably higher porosity and plasticity. Mulch obtained from branches of the Canarian palm tree (*Phoenix canariensis*) has been tested as substrate for mixed flow, intermittently fed treatment wetland mesocosms processing high strength urban wastewater. The effect of the presence of plants (*Phragmites* and *Cyperus*), influent pressure and hydraulic loading rate was studied. The best removals (SS: 89%, COD: 77%, turbidity: 82%) have been obtained with planted reactors treating highly concentrated influents at the lower hydraulic loading rates tested. The palm tree mulch units achieved similar removals of SS, COD and turbidity to one having gravel as substrate and planted with common reed. Mulch obtained from stems of giant reed (*Arundo donax*) provided similar removals of SS and turbidity but that of COD was lower. The combination of organic-based TWs with gravel-based ones provided high removals (SS: 95%, COD: 78%, turbidity: 95%) while the risk of clogging was strongly reduced.

1. Introduction

The basic components of treatment wetlands (TWs) are the substrate (usually gravel), biofilm, plants and water. In the particular case of subsurface flow TWs, their performance and life span greatly depend on the substrate, clogging being one of the most important problems of this wastewater treatment technology. In this sense, the concentration of suspended solids (SS) in the influent is a key parameter to be controlled as high SS loading rates would lead to faster clogging by means of the physical filling of the substrate pores. It is also known that most solids are settled near the inlet zone of TWs (Caselles-Osorio et al., 2007). For high-strength wastewaters, a pre-treatment aimed at reducing the concentration of SS should be employed before treatment with subsurface flow TW. However, low SS alone does not prevent clogging as biodegradable organic matter can help to develop biofilm clogging (Caselles-Osorio and García, 2006). Thus, in addition to SS loading rate, that of COD should also be low enough to control the development of biofilm. Clogging problems in vertical flow treatment wetlands (VF) seemed to be minimized with COD and TSS loading rates below 20 g/m^{2}d and 5 g/m^{2}d, respectively (Winter and Goetz, 2003).

Gravels of different diameters have usually been employed as substrate of TWs. This or any other mineral medium has a fixed “hosting capacity” for solids which is determined by its porosity. An alternative substrate material with a reduced clogging risk would be one made of mulch. Within the limits of the Campus of Tafira (Gran Canaria, Canary Islands, Spain) there is a well preserved Canarian palm tree (*Phoenix canariensis*) forest. This species is present in all the Canary Islands and it has been introduced as an ornamental plant in many places around the world. However, as the palms grow, dry branches fall down and accumulate around the tree trunks increasing the risk of fire, particularly in the long, dry summers of the Archipelago. Once triturated, the dry branches (mulch) have been successfully employed as soil amendment and in the production of compost. In addition to this, the giant reed (*Arundo donax*) has become an environmental concern in the

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Canary Islands because of its invasive character and ability to propagate forest fires (Arévalo et al., 2005). To find a new application for these forest wastes, the performance of TW mesocosms using palm tree and giant reed mulches as substrates was studied with the main goal of removing SS, as they are considered to be the first cause of clogging of TWs (Knowles et al., 2011). Some of the potential advantages of using these organic substrates instead of a mineral one (gravel) are the following:

- Regarding environmental aspects, the mulch is obtained from a waste that must be periodically removed to reduce the risk of fire in palm forests, while using the mineral substrate (gravel) implies mining activity with an associated environmental impact. In addition to this, the organic substrate is renewable, locally available and abundant.
- Regarding wastewater treatment in TWs, organic substrates can enhance plant settlement and growth, adsorb organic pollutants more efficiently and host a larger amount of SS before becoming clogged due to their greater porosity. Thus, using an organic-based TW previously to a mineral-based TW can enlarge the life span of the latter.

However, considering the potential advantages of organic-based TWs the existing literature on their use for wastewater treatment is still scarce. For instance, Aslam et al. (2007) compared gravel and compost-based VFs for the treatment of refinery wastewaters and found that the compost-based TW provided better BOD and COD removals. Tee et al. (2009) compared rice husk and gravel-based TWs and the effect of plants on the removal of nitrogen and phenol. The presence of plants and the organic substrate improved the elimination of phenol. These authors attributed these results to the larger mass of rhizomes developed by the plants in the organic substrates. Saeed and Sun (2011) compared three hybrid systems (vertical-horizontal) containing wood mulch, gravel and a mixture of both. The VFs with mulch removed more ammonia, total nitrogen, total phosphorus and BOD. Nevertheless, the horizontal flow TWs (HFs) with gravel worked better than the corresponding ones with mulch because the former released organic matter, phosphorus and SS to the effluent. Wang et al. (2010) employed an organic-based VFs for the treatment of liquid sludge. Their goal was to determine if the designed TW could be used to treat sludge and the role of plants on the quality of the effluent. The results showed the feasibility of using the TW for the treatment of sludge containing high concentrations of organic matter. No clogging problems appeared during the experimental time and the presence of the plants, particularly *Phragmites* improved treatment.

The goals of the present study were to explore the feasibility of using palm tree and giant reed mulches as substrates in TWs as pretreatment of high strength urban wastewaters, to determine the effect of the presence of plants, influent pressure and hydraulic loading rate on the performance of organic-based TWs and to compare the performance of palm tree mulch TWs to that of conventional gravel-based ones.

2. Material and methods

2.1. Analysis of water and palm tree mulch

Water quality parameters (BOD_5, COD, SS and turbidity) were measured in unfiltered, homogenized samples as described by standard methods (APHA, 2005). Hence, total BOD_5 and COD were measured. BOD_5 (henceforth BOD) can include nitrification as no inhibitor was added. NH_4^+-N was determined with a selective electrode from Crison (Barcelona, Spain). PO_4^{3-}−P was determined as molybdate-reactive phosphate (Murphy and Riley, 1958).

The elemental composition of the palm tree mulch was determined after sterilization in autoclave, drying (110 °C for one week), trituration and sieving. The fraction with particle size between 106 and 250 ìm was washed with milli-Q water in a vacuum filtration system to remove color and other impurities. Then, the so-treated material was dried again at 100 °C for 24 h. The elemental analysis was performed with a 1112, FlashEA Elemental Analyzer (Thermo Electron Corporation, Milan, Italy).

2.2. Description of the TWs

The TWs employed in this study were 275-L polypropylene recipients (length: 1.17-m, height: 0.48-m, width: 0.49-m) from Progarden (Italy). The water flow used was mixed, i.e. the inlet was located at the top of the recipient and the outlet at the bottom of the opposite side (Table 1). According to the substrate and plant used, the following nomenclature was used:

- **PM+r**: palm tree mulch with common reed (*Phragmites*).
- **PM**: only palm tree mulch without plant as a control.
- **PM+C**: palm tree mulch with *Cyperus*.
- **AdM**: substrate obtained from giant reed (*Arundo donax*) without plant. This substrate was prepared by manually cutting fragments of giant reed stems, thus the resulting fragments (3–10 cm long) were notably larger than those of palm tree mulch.
- **Gravel**: basaltic gravel (gravel: 99.8%, sand: 0.1%) with an average diameter of 6.5-mm and d10-d60: 4.11–5.51 mm, planted with common reed. This unit was used as control for comparison purposes. The total surface area of the reactor bed was calculated to be 128.5 m^2 according to Lyew and Sheppard (1997).

The porosity of the substrates was determined directly with water. The porosity of the gravel was 49%, that of the wet palm tree mulch was 56% and that of giant reed mulch was 83%.

The height of the palm tree and giant reed mulch substrates was 25-cm while that of gravel was 40-cm. Organic-based TWs were shallower than gravel-based ones because the former were thought to be used as a primary treatment of high-loaded urban wastewater. Considering that SS are retained mainly on the surface of palm tree mulch, it was decided to provide an accumulation zone for SS. The reactors were prepared at the beginning of August, 2011. During August and September, wastewater from the Campus was intermittently added to wash the substrate, to allow the plants to develop their rhizomes and the bacterial population to colonize the substrate. During this period the mulch volume was reduced by one third approximately because of the compacting effect of water. Hence, more mulch was added to achieve the required substrate height.

2.3. Measurement of daily inflows and hydraulic loading rates

The influent was collected from a 17-m^3 tank with a timer-controlled triturating pump. Daily inflows were measured for each reactor by collecting the effluent in recipients located below them. With the help of a pump and a flow-meter, the volume of water was measured and referred to the collection time and reactor surface. Hydraulic loading rates (HLR) values are provided in L/m^2d.

2.4. Experimental periods

The experiments were performed outdoors in the Campus of Tafira, (University of Las Palmas de Gran Canaria, Canary Islands, Spain). The preliminary experimental period of this work (Table 1) was designed to determine if it was possible to substitute septic and