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Nitrogen and phosphorus removal and *Typha domingensis* tolerance in a floating treatment wetland

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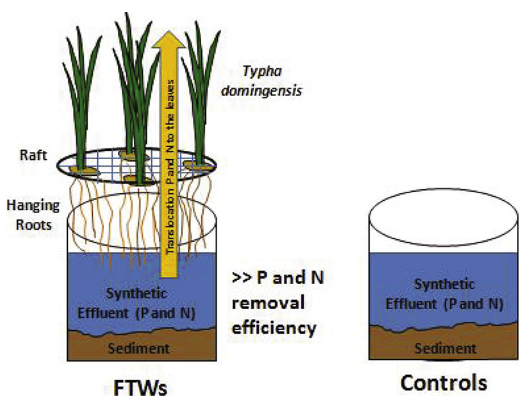
HIGHLIGHTS

- Treatment of synthetic runoff effluent was evaluated with *T. domingensis* FTWs.
- P was efficiently removed by FTWs and plants tolerated the effluent conditions.
- Nitrate removal was higher in FTWs than in the controls along the experiment.
- N and P were mainly accumulated in plant tissues and not in the sediment.
- FTWs are a promising strategy to treat water bodies affected by runoff.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim of this work was to study the efficiency of microcosms-scale floating treatment wetlands (FTWs) in the N and P removal from a synthetic runoff effluent and to evaluate the effluent tolerance of *Typha domingensis*. Each FTW consisted of a raft constructed with a plastic net where *T. domingensis* plants were installed. In order to evaluate the plant role, reactors with FTWs and without FTWs (controls) were used. P and N additions were carried out as follows: 5 mg L^{-1} P (P5 and P5-control); 10 mg L^{-1} N (N10 and N10-control); 5 mg L^{-1} P + 10 mg L^{-1} N (P5N10 and P5N10-control). Also, a biological control (B-control) without contaminant addition was used. The removal of soluble reactive phosphorus and total phosphorus were significantly higher in the FTWs than in the controls. Ammonium and nitrate concentrations were not significantly different between FTWs and controls at the end of the experiment. However, nitrate concentrations showed significant differences between FTWs and controls during the experiment. N and P were mainly accumulated in plant tissues and not in the sediment. Plants tolerated the effluent conditions and showed a positive growth rate. The use of FTWs is a promising strategy for the sustainable treatment of water bodies affected by runoff waters.

1. Introduction

Floating treatment wetlands (FTWs) consist of a buoyant artificial medium, which facilitates root development in the water column (Borne, 2014; Tondera et al., 2017; Vymazal, 2007). FTWs employ emergent macrophytes growing in a floating mat on the water surface rather

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than rooted in the bottom sediment (Headley and Tanner, 2012). These macrophytes are characterized by the presence of large aerenchyma in their roots and rhizomes, which increases their buoyancy potential (Chen et al., 2016). Plant roots provide an extensive surface area for the growth of the attached biofilm and entrapment of suspended particulate matter (Borne, 2014). Since the plants are not rooted into the bottom sediment, they are forced to obtain nutrients directly from the water column, enhancing nutrient accumulation into their biomass (Fonder and Headly, 2010; Tanner and Headley, 2011).

FTWs are appropriate to treat water bodies contaminated with different types of wastewaters (Chen et al., 2016).The use of FTWs has included the treatment of storm water (Tanner and Headley, 2011), sewage (Ash and Troung, 2003; Van de Moortel et al., 2011), piggery effluent (Hubbard et al., 2004), pond water (Kato et al., 2009), urban lake water (Guimarães et al., 2000), dairy manure effluent (Sooknah and Wilkie, 2004), and water supply reservoirs (Garbutt, 2004). Besides, FTWs have been studied for the treatment of urban runoff (Fonder and Headly, 2010; Tanner and Headley, 2011). More recent works have focused on the potential performance improvement of FTW in N removal by the addition of thiosulfate (Gao et al., 2018), and the assessment of FTW performance to improve water quality in a eutrophic urban pond (Olguín et al., 2017).

The city of Santa Fe (Argentina) is located in the Middle Parana River floodplain. It is surrounded by natural wetlands receiving urban runoff effluents that deteriorate their quality. FTWs could be suitable for the treatment of these urban runoff effluents. The aim of this work was to study the efficiency of microcosms-scale FTWs in N and P removal from a synthetic runoff effluent, and to evaluate the effluent tolerance of *Typha domingensis*.

2. Materials and methods

2.1. Experimental design

T. domingensis plants, sediment and water were collected from an unpolluted pond of the Paraná River floodplain near Santa Fe City, Argentina. The water physicochemical composition of this pond was (mean ± standard deviation): pH = 7.2 ± 0.1; conductivity = 223 ± 1 μS cm^{-1}; dissolved oxygen (DO) = 6.71 ± 0.10 mg L^{-1}; soluble reactive phosphorus (SRP) = 0.025 ± 0.002 mg L^{-1}; NH_4^+ = 0.790 ± 0.005 mg L^{-1}; NO_3^- = 0.310 ± 0.005 mg L^{-1}; NO_2^- = non detected (detection limit = 5 μg L^{-1}); Ca^{2+} = 9.1 ± 0.1 mg L^{-1}; Mg^{2+} = 2.0 ± 0.2 mg L^{-1}; Na^+ = 32.8 ± 0.5 mg L^{-1}; K^+ = 14.1 ± 0.5 mg L^{-1}; Fe = 0.291 ± 0.005 mg L^{-1}; Cl^- = 14.6 ± 1.0 mg L^{-1}; SO_4^{2-} = 10.5 ± 1.0 mg L^{-1}; total alkalinity = 97.2 ± 1.2 mg L^{-1}. Only healthy plants of a uniform size and weight were selected. Plants were pruned to be carried to the greenhouse.

Plastic reactors (70 L) were installed outdoors under a semi-transparent plastic roof. All reactors contained 4 Kg of sediment and water from the sampling pond. In the reactors, this sediment mass generates a layer of 3–4 cm depth. According to previous studies, this is the layer of sediment involved in the exchange reactions (Di Luca et al., 2011). To evaluate the plant role in contaminant removal, reactors with and without FTWs were used. Each FTW consisted of a raft constructed with a plastic net (surface area: 0.10 m^2) where 4 plants were disposed. Buoyancy was provided by a PVC frame (diameter: 12.7 mm). Rafts were designed to allow roots and rhizomes to remain submerged and hanging in the water column while aerial parts are kept above the surface. Reactors without FTWs were installed as controls without plants, only with sediment (Fig. 1).

After an acclimation period of 15 days, during which plants demonstrate a suitable growth in FTWs, they were pruned again to a height of approximately 20 cm, and reactors were drained. Subsequently, 38 L of synthetic effluent containing P and N were added to the reactors with FTWs and controls. One reactor was used as a biological control (with FTW and sediment, and without contaminant addition). Reactors were arranged in triplicate, as follows:

FTWs treatments:	Controls:
-5 mg L^{-1} P (P5)	- 5 mg L^{-1} P (P5-control)
- 10 mg L^{-1} N (N10)	- 10 mg L^{-1} N (N10-control)
- 5 mg L^{-1} P + 10 mg L^{-1} N (P5N10)	- 5 mg L^{-1} P + 10 mg L^{-1} N (P5N10-control)
- Biological control (B-control)	

Stock solutions of NH_4NO_3 and KH_2PO_4 and water from the sampling pond were used to prepare the synthetic effluent. P and N concentrations used in this work were chosen due to they were usual concentrations in a peri-urban wetland that receive stormwater, domestic, and sewer flows (data not shown). Water level in the reactors was maintained by adding water from the sampling site. During the experiment, air temperature ranged from 21.1 to 34.5 °C. The experiment lasted 28 days and it was performed in triplicate.

In each reactor water was sampled at 0, 1, 3, 7, 10, 14, 21 and 28 days. Conductivity, pH, soluble reactive phosphorus (SRP), total phosphorus (TP), N-NH_4^+ and N-NO_3^- were measured periodically in all treatments. Sediment and plants were sampled at the beginning and the end of the experiment. Sediment was sampled using a 3-cm diameter PVC corer and plants were separated into roots, rhizomes and leaves. In the sediment, pH and Eh were measured in all treatments. TP and total Kjeldahl nitrogen (TKN) concentrations in plant tissues and sediment were determined.

2.2. Chemical analysis

The water samples were kept refrigerated until their analysis. Conductivity, dissolved oxygen (DO) and pH in water were measured with a multi-parameter probe brand WTW, model: Multi 3510 IDS. Water samples were filtered with Millipore filters (0.45 μm). Analytical determinations were carried out according to APHA (2012). SRP was determined by the colorimetric technique of molybdenum blue (Murphy and Riley, 1962) (Perkin Elmer Lambda 20 UV–VIS Spectrophotometer). TP was determined by digestion of the sample with nitric acid and sulphuric acid (APHA, 2012), neutralization and determination of phosphate by the method of Murphy and Riley (1962). NH_4^+ and NO_3^- were determined by potentiometry (Orion ion selective ion electrodes 95-12 and 93-07 respectively, sensitivity: 0.01 mg L^{-1} N, reproducibility: ±2%).

TP concentrations in leaves, roots, rhizomes and sediment were determined at the end of the experiment. Plant samples were washed with tap and distilled water, and subsequently plant and sediment samples were oven-dried at 60 °C for 48 h. TP concentrations were determined, after digestion with HCl:HNO_3 (USEPA, 1994), by the colorimetric technique of molybdenum blue (APHA, 2012; Murphy and Riley, 1962) (UV-VIS Spectrophotometer Perkin Elmer Lambda 20). TKN in plant tissues and sediment were determined by the Semi-micro Kjeldahl method according to APHA (2012).

The pH and redox potential (Eh) of the sediment was determined potentiometrically with an Orion pH/mV-meter. Redox potential was measured *in situ*, and pH was measured in a sediment suspension: water 1:2.5.

P and N amounts (mg) were estimated by multiplying P or N concentrations in plant tissues and sediment (mg g^{-1} dry weight) by biomass (g dry weight).

2.3. Plant study

Plant height was measured, and the external appearance of plants was observed daily, to detect possible senescence. Chlorophyll concentration was measured at the beginning and at the end of the experiment. Relative growth rate (RGR) (cm cm^{-1} day^{-1}) was calculated in each