Journal of Environmental Management 190 (2017) 197–207

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Phosphorus retention and fractionation in an eutrophic wetland: A one-year mesocosms experiment under fluctuating flooding conditions

María del Carmen Tercero, José Álvarez-Rogel, Héctor Miguel Conesa, Isabel Párraga-Aguado, María Nazaret González-Alcaraz*

Departamento de Ciencia y Tecnología Agraria, Escuela Técnica Superior de Ingeniería Agronómica, Universidad Politécnica de Cartagena, Paseo Alfonso XIII 48, Cartagena, 30203, Murcia, Spain

ARTICLE INFO

Article history:
Received 13 October 2016
Received in revised form
26 November 2016
Accepted 24 December 2016

Keywords:
Phragmites australis
Green filters
Mar Menor lagoon
Phosphorus dynamics
Wetting-drying cycles

ABSTRACT

This study aimed to evaluate the response of salt marshes to pulses of PO_4^{3-}-enriched water, with and without the presence of *Phragmites australis*. A one-year mesocosms experiment was performed in simulated soil profiles (fine-textured surface layers and sandy subsurface layers) from a coastal salt marsh of the Mar Menor lagoon under alternating flooding-drying conditions with eutrophic water, under low (1.95 mg L^{-1} P-PO_4^{3-}) and high (19.5 mg L^{-1} P-PO_4^{3-}) P load, and with the presence/absence of *Phragmites*. The PO_4^{3-} concentrations in soil porewater and drainage water were regularly measured, and P accumulated in soils (including a fractionation procedure) and plants (roots, rhizomes, stems and leaves) were analyzed. The experimental mesocosms were highly effective in the removal of P from the eutrophic flooding water (>90% reduction of the P added to the system both in the soil pore water and drainage water), regardless of the nutrient load, the season of the year and the presence/absence of *Phragmites*. The soil was the main sink of the P added to the system, while *Phragmites* had a minor role in P removal. The biomass of *Phragmites* accumulated ~27% of the P added with the flooding water in the treatment with water of low P load while ~12% of P in that of high P load; the rhizomes were the organs that contributed the most (~67–72% of the total P retained by the plants). Ca/Mg compounds were the main contributors to the retention of P in the soil compartment, especially in the fine-textured surface soil layers (~34–53% of the total P in the soil was present in this fraction). *Phragmites* favored the retention of P onto metal oxides (~12% increase of the P retained in the metal oxides fraction in the treatment with water of high P load). Hence, the use of constructed wetlands to ameliorate the negative impacts of P-enriched waters in the Mar Menor lagoon and similar areas is recommended. We propose the incorporation of fine-textured carbonated materials, with high content of Ca/Mg compounds, and the use of *Phragmites* to favor the retention of P by these systems.

1. Introduction

Territories with intensive agricultural, urban and/or industrial activities are prone to suffer eutrophication problems due to the massive use of fertilizers and the high production of wastewaters (Di and Cameron, 2002; Robertson et al., 2013). While wetlands are likely to receive polluted water and sediments from the surrounding zones, these systems have also the capacity to transform and/or deplete harmful compounds (e.g. nutrients), acting as green filters (Mitsch and Gosselink, 2007; Zhang et al., 2014). In this sense, wetlands are considered eco-friendly systems suitable for improving water quality coming from point and diffuse sources in catchments with intensive use (Cooper, 2009; Tournebize et al., 2016). Particularly, it is well known that wetland soils might act as phosphorus (P) sinks, contributing to reduce the concentration of this nutrient in the water flowing through them (Wang and Li, 2010; González-Alcaraz et al., 2012a; Canga et al., 2016). This capacity to remove P from water is influenced by processes such as sorption, precipitation and plant uptake (Vymazal, 2007). Machado et al. (2017 and references cites therein) highlighted the

* Corresponding author.
E-mail address: nazaret.gonzalez@upct.es (M.N. González-Alcaraz).

http://dx.doi.org/10.1016/j.jenvman.2016.12.060
0301-4797/

characteristics of the substrate as a key aspect in P retention.

Between 80 and 90% of the P in wetlands is stored in the soil compartment (Vepraskas and Faulkner, 2001), being organic matter, Ca and Mg compounds and metal oxides and hydroxides the main components involved (Reddy and DeLaune, 2008). The retention of P in the soil is mainly controlled by soil physico-chemical characteristics (e.g. pH, redox potential -Eh-, mineralogy, organic matter, clay content, Ca compounds, metal oxides, etc.), although other factors such as vegetation, water-table depth, hydraulic retention time and flooding fluctuations might also affect (Reddy et al., 1999). Under high pH conditions P binding onto Ca compounds is the main retention process in the soil/sediment (Vohla et al., 2011), while Al and Fe compounds have a more relevant role in acidic environments (Verhoeven et al., 1999). However, and under certain situations, wetlands might be transformed from sink into sources of P due to the biogeochemical processes occurring in the soil-water system (Song et al., 2007), hence increasing the eutrophication risks for the nearby water bodies (Karstens et al., 2015).

The Mar Menor lagoon (SE Spain) and its surrounding areas (Campo de Cartagena plain) represent a clear example of a Mediterranean territory with strong impacts due to human activities. The lagoon hosts a number of international environmental protection figures. It is one of the largest coastal lagoons (135 km^2 surface area) of the Mediterranean basin and is included in the Ramsar Convention of Wetlands. It is a Special Protected Area of Mediterranean Interest (SPAMI), a Special Protected Area (SPA) under the EU Wild Birds Directive and a Site of Community Importance (SCI) to be integrated into the Nature 2000 Network (EU Habitats Directive). However, the surrounding territories host intensive agricultural activities and high urban pressure that have led to strong environmental impacts on the lagoon (Conesa and Jiménez-Cárceles, 2007; Jiménez-Martínez et al., 2016).

Previous field studies in the Mar Menor area have found extremely high concentrations of P (until ~15 mg L^{-1}), nitrogen —N— (until ~120 mg L^{-1}) and dissolved organic carbon -DOC- (until ~100 mg L^{-1}), of agricultural and urban origin, in watercourses (called *ramblas*) flowing into the territory. Some studies have shown that when this eutrophic water flows throughout the coastal salt marshes, before reaching the Mar Menor lagoon, it is depurated (Álvarez-Rogel et al., 2006; Jiménez-Cárceles and Álvarez-Rogel, 2008), while the water that directly reaches the lagoon actively contributes to its eutrophication (García-Pintado et al., 2007). However, and because there is an important seasonal variability (both in quantity and quality) in the pulses of nutrient-enriched water related with changes in the anthropogenic activities during the year (e.g. González-Alcaraz et al., 2012b), it is necessary to better understand the behavior of these wetlands in a scenario of intermittent pulses of polluted water, to properly assess their performance and management. Furthermore, the rainfall regime of the area, consisting on dry periods in alternation with short intensive storm events, contributes to the described phenomenon since it provokes flash-flood events that mobilize large amounts of nutrients into the Mar Menor lagoon in punctual moments of the year (Moreno-González et al., 2013).

The paper is part of a wider study, performed at mesocosms scale, in relation to the behavior of the soil-plant system of the coastal salt marshes of the Mar Menor lagoon in response to the nutrient-enriched water pulses in the presence or absence of *Phragmites australis* (Cav.) Trin ex Steud (common reed). The data about the biogeochemical processes in the rhizosphere and the N cycle have been previously published (Tercero et al., 2015; Álvarez-Rogel et al., 2016). The aforementioned papers showed that: 1) the presence of *Phragmites* and the nutrient level in the flooding water modified the physico-chemical and microbiological soil properties at different depths, which was modulated by the changes in the soil temperature and the physiological activity of the plants throughout the year; 2) more than 80% of nitrate (NO_3^-) was removed by denitrification, regardless of the presence of *Phragmites*, but a tendency to lower potential soil emissions of nitrous oxide (N_2O) was observed in the presence of plants.

The aim of the present study was to evaluate the response of the salt marshes to pulses of eutrophic water with high load of phosphate (PO_4^{3-}), with and without the presence of *Phragmites*, in order to increase our knowledge about the role of these systems as sinks or sources of P. In addition, we provide some recommendations for the management of these wetlands to improve their role against eutrophication by surplus of P. The specific objectives were: 1) to evaluate the capacity of P removal from the soil porewater and to ascertain if this capacity is influenced by the PO_4^{3-} concentrations in the flooding water, the season of the year and the presence/absence of *Phragmites*; 2) to determine the contribution of different soil components and different tissues of *Phragmites* to P retention. For this purpose, a one-year mesocosms experiment was performed under alternating flooding-drying conditions with eutrophic water enriched in P, N and organic carbon at two concentrations, and with the presence and absence of *Phragmites*. The PO_4^{3-} concentrations in soil porewater and drainage water were regularly measured, and P accumulated in soils (including a fractionation procedure) and plants (roots, rhizomes, stems and leaves) were analyzed. Based on previous field studies in the area that determined that soil plays a main role in P retention (Jiménez-Cárceles and Álvarez-Rogel, 2008; González-Alcaraz et al., 2012b), we hypothesized that these salt marshes are highly effective in PO_4^{3-} removal throughout the year, irrespective to the presence/absence of *Phragmites*, but that the role of the plants could be modulated by the P load in the eutrophic flooding water.

2. Materials and methods

2.1. Field sampling and initial soil characterization

The soils and plants used in this study were collected from the Marina del Carmoli salt marsh, the largest coastal salt marsh of the Mar Menor lagoon (SE Spain; N 37° 41′ 42″, W 0° 51′ 31″; Fig. S1, Supplementary material). The typical soil profile of this marsh consists on a loam to silty loam surface layer and a sandy subsurface layer (Álvarez-Rogel et al., 2007). Three types of samples were taken from the salt marsh: 1) surface soil (top 25 cm) and the corresponding plants of *Phragmites* (aerial and belowground parts) growing in it were collected from a stand of this species; 2) surface soil (top 25 cm) collected from a bare area next to the aforementioned *Phragmites* stand; 3) sand was collected from a dune area of the salt marsh located next to zones 1 and 2.

Table S1 (Supplementary material) shows the main characteristics of the soils and sand collected. Both soils were alkaline (pH ~7.9–8.1), carbonated (total $CaCO_3$ ~28–31 g kg^{-1}) and fine textured (clay + silt content ~69%). The soil collected from the *Phragmites* stand had higher content of organic matter (total organic matter determined as loss on ignition -LOI- ~6.8% vs. ~5.9%) and total nitrogen (TN ~0.19% vs. ~0.14%) and it was slightly less saline (electrical conductivity -EC- ~1.5 dS m^{-1} vs. ~3.2 dS m^{-1}) than the soil from the bare area. The sand was alkaline (pH ~8.7), carbonated (total $CaCO_3$ content ~59 g kg^{-1}), scarcely saline (EC ~0.2 dS m^{-1}) and with very low content of organic matter (LOI ~3.5%) and total nitrogen (TN ~0.08%). A complete description of the characterization procedure is available in Tercero et al. (2015).