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Nitrogen removal in pilot-scale partially saturated vertical wetlands with and without an internal source of carbon

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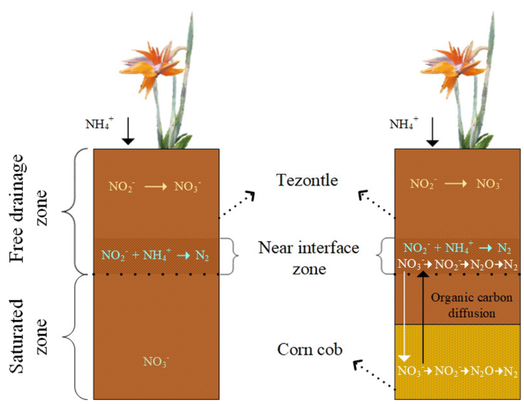
HIGHLIGHTS

- Partially-saturated vertical wetlands with corncob showed higher removals for TN.
- Corncob allowed denitrification both in the aerobic zone and in the anoxic zone.
- ANNAMOX was responsible for TN in the systems without corncorb.
- In these systems ANNAMOX took place in the aerobic zone.

GRAPHICAL ABSTRACT



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ABSTRACT

The aim was to evaluate and compare total nitrogen (TN) removal in pilot-scale partially saturated vertical wetlands (PSVWs) with and without an internal solid source of organic carbon (corncob) in order to distinguish the role of nitrification-denitrification and ANAMMOX in the removal process. The height of the free-drainage zone (FDZ) was 40 cm and the saturated zone (SZ) was 30 cm in system I (SI) and system II (SII) and 40 cm in system III (SIII) and system IV (SIV). In SII and SIV, approximately 30 kg of dry, 5 cm–length corncob was added. The systems were evaluated during two periods, that is, P1 and P2. Measurements of water quality parameters including BOD_5, COD, organic nitrogen (Org-N), ammonium, nitrate and nitrite were taken in the influent and effluents on a weekly basis; nitrate measurements were also taken at the interface. Measurements of pH, dissolved oxygen (DO) and oxidation-reduction potential (ORP) were taken in the SZ. The height of both SZ (40 cm vs. 30 cm in P1) and FDZ (40 vs. 25 and 30 cm in SI/SIII in P2) did not affect the efficiencies ($p > 0.05$) but the presence or absence of corn cob did ($p < 0.05$). Thus, SII and SIV were superior when compared to SI and SIII ($p < 0.05$) with TN average removal efficiencies of 72.9% and 73.2% in P1, and 59.8% and 64.2% in P2, respectively; showing a tendency to lower values when the biodegradable organics supplied by the corncob diminished. In SI and SIII, TN removals were 47.6% and 40.3% in P1, and 46.1% and 44.1% in P2, respectively. In SII and SIV, denitrification took place in both the lower semi-saturated part of the FDZ (probably also ANAMMOX) and SZ; whereas in SI and SIII, ANAMMOX took place in the lower semi-saturated part of the FDZ.

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1. Introduction

Nitrogen removal along with phosphorus removal remains a challenge in treatment wetlands (TW), although this technology is considered a better option when compared to conventional technologies not designed specifically for nitrogen removal (Metcalf and Eddy, 2003). Nitrogen is present in wastewater in both organic and inorganic forms and its removal from wastewater implies complex biochemical transformations. Nitrification-denitrification mediated by microorganisms is still considered as the major route for total nitrogen removal in TWs (Li et al., 2014). However, another important microbial pathway is the anaerobic ammonium oxidation (ANAMMOX) where ammonium is oxidized to molecular nitrogen by nitrite under anoxic/anaerobic conditions (Dong and Sun, 2007; Saeed and Sun, 2012). The main difficulties for nitrogen removal arise from the fact that nitrification is inhibited in the presence of a high content of organic compounds that consumes dissolved oxygen in its biodegradation process while denitrification is limited without the presence of biodegradable organics (Saeed and Sun, 2012).

Total nitrogen removal tend to be higher in horizontal subsurface flow wetlands (HSSFW) in comparison to vertical subsurface flow wetlands (VSSFW) due to the simultaneous presence of aerobic conditions surrounding the roots and the anoxic-anaerobic conditions in the zones beyond the rhizosphere in HSSFWs (Hua et al., 2017). According to Vymazal (2007), the mean removal of total nitrogen in 137 horizontal subsurface flow wetlands was 42%. With regard to VSSFWs, their high capacity for nitrification in comparison to HSSWs is well-known. The predominance of aerobic conditions in this type of TWs along with the depletion or reduction of BOD to low levels limit the subsequent denitrification, so in general, total nitrogen (TN) removal is very low or even null (Langergraber et al., 2008; Masi and Martinuzzi, 2007; Torres-Bojorges et al., 2017). Such situation is very common particularly in those cases when the C/N ratio is low in the wastewater to be treated (<2.5) (Saeed and Sun, 2012). Even in VSSFW-HSSFW hybrid wetlands, in which the objective is to promote the nitrification-denitrification process, the removal of TN has been found to be low due to the aforementioned depletion of BOD in the first stage and the insufficient organic carbon provided by the vegetation in the HSSFWs; unless and external soluble carbon source is supplied to the system, in the form of methanol, ethanol, acetic acid, glucose (Shen et al., 2013) or fructose, whose use could be expensive (Yang et al., 2018).

One option to solve this issue regarding nitrogen removal is the use of a very recent type of vertical wetland, i.e., partially saturated vertical wetlands (PSVW) (Pelissari et al., 2017; Silveira et al., 2015). In this type of wetlands, nitrification is performed in the free-drainage zone while denitrification takes place in the saturated bottom; nevertheless, in wastewater with low C/N ratio, the depletion of BOD could still be the factor that prevent the desirable denitrification. Thus, in some cases, the addition of a source of organic carbon could still be required. An alternative to the expensive soluble organic carbon could be those solid organic agro industrial residues that are cheap and easily obtained in developing countries such as Mexico. Therefore, in this study the aim was to evaluate and compare TN removal in pilot-scale PSVWs with and without an internal solid source or organic carbon (corncob) in order to distinguish the role of nitrification-denitrification and ANAMMOX in the removal process.

2. Material and methods

2.1. Description of the experiment

This study was conducted during 17 months, from March 2016 to July 2017 under a subtropical climate at 1530 m above sea level and an annual average temperature of 21 °C. Four pilot-scale PSVWs identified as SI, SII, SIII and SIV were evaluated for TN removal. The dimensions of the PSVWs were 48 cm × 48 cm × 80 cm (L × W × H). The height of the free-drainage zone (FDZ) was 40 cm in all the systems while the saturated zone (SZ) at the bottom was 30 cm in SI and SII and 40 cm in SIII and SIV (Fig. 1). In addition, in SII and SIV, along 25 cm of the SZ, 5 cm–length dry corncob was added (approximately, 30 kg). The quantity of corncob was selected to have a minimum distance of 5 cm between the corncob zone and the FDZ, preventing in this way, the interference of corncob with the complete wastewater drainage along the FDZ. The systems were intermittently fed with sedimented wastewater generated in the Centro Universitario de la Ciénega of the University of Guadalajara, in Jalisco, Mexico, by a pump programmed to discharge 2.8 L every 2 h onto the surface. Each system was planted with one adult plant of *Strelitzia reginae*. Ground tezontle with d_{10} of 0.48 mm and d_{60} of 1.90 mm, was used as filter medium. The systems were protected from receiving any rainfall by open-sided coverings.

2.2. Stages of the experiment

The systems were provided a stabilization period of three months, after which the first monitoring period (P1) of seven months began. After P1, SI and SIII (without an internal carbon source) were modified, in order to promote partial nitrification and in turn, increase the ANAMMOX process. The FDZ was reduced to 25 cm in SI and to 30 cm in SIII; while the saturated zone was maintained in 30 cm in the two systems (Fig. 2). After this modification, the four systems were evaluated for another second period of seven months (P2).

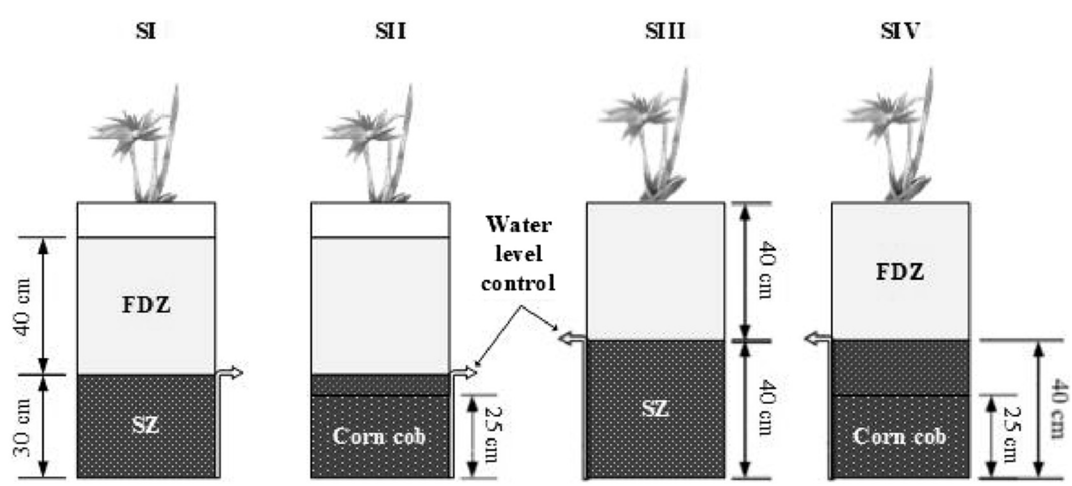

Fig. 1. Four pilot-scale PSVWs evaluated for nitrogen removal in P1. FDZ: free-drainage zone; SZ: saturated zone.