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Review

A review on the main affecting factors of greenhouse gases emission in constructed wetlands

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ABSTRACT

Constructed wetlands (CWs) are natural-like systems for wastewater treatment capable to remove both pollutants and nutrients without additional energy demand. In these systems, gaseous compounds are released into the atmosphere through microbial processes. Among these gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the most dangerous because they act as greenhouse gases (GHGs) and are well known as contributory factors to cause global warming. In this paper we reviewed 224 scientific articles (from 1980 to 2016) from the literature in order to analyze the most important factors that drive the quantity and type of GHGs production and emission from different CWs systems. Wastewater flow and composition, hydroperiod, environmental conditions and plant presence and species used to vegetate CWs have been considered. CWs typologies influence GHGs fluxes with lower CH_4 emissions from subsurface flow CWs than free water surface (FWS) ones and higher N_2O emissions from vertical subsurface flow (VSSF) CWs than FWS ones. The inlet wastewater COD/N ratio of 5:1 has been found as the best ratio to obtain in the same time the lowest N_2O emission and the highest nitrogen removal in FWS CWs. The inlet wastewater C/N ratio of 5:1 allows to obtain the lowest CO_2 and CH_4 emissions in VSSF CW treatment. Intermittent CWs bed wastewater loading decreases CH_4 and promote CO_2 and N_2O emissions. Temperature is positively correlated with CO_2, CH_4 and N_2O emissions and solar radiation with CO_2 and CH_4 emissions. GHGs flux is affected by plant presence and species, and it is influenced both by the phenology and density of vegetation. Plant presence significantly increases the CO_2 emission respect to unvegetated condition in all CWs types, and increases N_2O and CH_4 emissions in VSSF CWs. Considering the HSSF CWs plant presence significantly reduce the CH_4 emissions. Plant species richness effect on CH_4 emission has been investigates in a limited number of papers with not unique results, probably due to the different plant species and number used by authors, which may have influenced the CWs microbial population and activity. Considering plant species *Zizania latifolia* determine significant higher CH_4 and N_2O emissions than *Phragmites australis*. No significant different CH_4 and N_2O emissions have been found between *P. australis* and *Typha latifolia*. Significant lower N_2O emissions determine the *T. angustifolia* than *P. australis.* Although plant presence, in some case, increases CW GHG emissions respect to unvegetated situation, the vegetation fixes atmospheric carbon by photosynthesis; as a consequence CWs act, in most cases, as sink of $CO_{2(eq)}$.

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1. Introduction

Constructed wetlands (CWs) are natural-like systems for wastewater treatment, which through various physical and biochemical mechanisms, based on substrate composition, microbes communities and plants ecosystems (Wang et al., 2008a,b) and operation strategy (Zhao et al., 2013; Wu et al., 2014), are capable to diminish pollutants present in wastewaters (e.g. Heavy metals, Phosphorus, Nitrogen, etc.) (Vymazal et al., 2006; Scholtz et al., 2007; Akratos et al., 2009) with significant less energy demand than conventional systems (Shao et al., 2013) having less influence on climate change throughout their life cycle (Zhao and Liu, 2013).

According Vymazal et al. (1998), CWs are classified considering the life form of the dominating macrophyte based systems as: free-floating, submerged, and emergent. These last systems, the most widely used, are further classified according their design in relation to the water flow in three major groups (Vymazal, 2007) as represented in Fig. 1: free water surface flow (FWS); horizontal subsurface flow (HSSF); vertical subsurface flow (VSSF); and combining the previous three types in to hybrid constructed wetland (HCW) systems.

FWS CW is a shallow sealed basin or sequence of basins, containing 20–30 cm of rooting soil, with a water depth of 20–40 cm with usually more than 50% of the surface covered by emergent planted and spontaneous vegetation (Vymazal, 2010). In this type of CWs frequently plants aboveground biomass is not harvested and the litter provides organic carbon necessary for denitrification. FWS CWs are efficient in removal of organics through microbial degradation and suspended solids through settling and filtration due to dense vegetation (Vymazal et al., 2006; Kadlec and Wallace, 2008). Nitrogen is removed mainly through nitrification (in water column) and subsequent denitrification (in the litter layer), and ammonia volatilization under higher pH values caused by algal photosynthesis.

HSSF CWs consist of gravel or rock beds – typically with a depth of 0.6–0.8 m in order to allow roots of wetland plants – sealed by an impermeable layer and planted with wetland vegetation. The wastewater is fed at the inlet and flows through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the outlet zone, where it is collected and discharged (Vymazal et al., 2006). Pollutants are removed by physic-chemical and biological processes in a network of aerobic, anoxic, anaerobic zones. The most important roles of macrophytes in this system type are provision of substrate (roots and rhizomes) for the growth of attached bacteria, radial oxygen loss (Brix, 1997; Nivala et al., 2013), nutrient uptake (Salvato and Borin, 2010; Lee et al., 2013; Vymazal, 2016) and insulation of the bed surface in cold and temperate regions (Brix, 1994). Organic compounds are removed mainly by microbial degradation under anoxic/anaerobic conditions due to the permanent saturation of the beds (Vymazal and Kröpfelová, 2008). Suspended solids are retained predominantly by filtration and sedimentation; nitrogen is mainly removed through denitrification whereas removal of ammonia is limited due to lack of oxygen in the filtration bed because of permanent waterlogged conditions (Vymazal, 2007).

VSSF CWs usually comprise a flat bed of graded gravel (Ø ca. 30–60 mm) topped with sand (Ø ca. 6 mm) planted with macrophytes (Vymazal et al., 2006). This CW type is fed intermittently with a large batch, thus flooding the surface. Wastewater then gradually percolates down through the bed, which allows air to refill the bed. This kind of feeding provides good oxygen transfer and hence the ability to provide suitable conditions for nitrification (Kadlec and Wallace, 2008), on the other hand, do not provide any denitrification (Vymazal, 2010). VSSF CWs are also very effective in removing organics and suspended solids (Maucieri et al., 2016). Recently, the “fill and drain” or “tidal” CWs have been developed. In tidal flow systems, the wastewater percolates upwards until the surface is flooded. When the surface is completely flooded, the feeding is stopped, the wastewater is then held in the bed and, at a set time later, the wastewater is drained downwards. After the water has drained from the filtration bed, the treatment cycle is complete and air can diffuse into the voids in the filtration material (Cooper, 2005).

The HCW systems derived from the combination in different ways of FWS, HSSF and VSSF CWs in order to achieve a higher treatment performance by using advantages of individual systems (Vymazal, 2013; Ávila et al., 2015; Maucieri et al., 2016).

To date the CWs are widely used to treat different wastewater types (Solano et al., 2004; Moir et al., 2005; Bulc, 2006; Borin and Tocchetto, 2007; Vymazal, 2009; Barbera et al., 2009; O'Geen et al., 2010; Vymazal, 2010; Verlicchi and Zambello, 2014; Pappalardo et al., 2016) and during their pollutant abatement processes release gaseous compounds into the atmosphere (Mander et al., 2003; VanderZaag et al., 2008). Among these gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the most dangerous for the environment because they act as greenhouse gases (GHGs) and are well known as contributing factors to cause global warming.

Already 20 years ago Nouchi et al. (1994) reported that CH_4 might be the dominant substance, which will contribute to warm the earth's surface. Thompson et al. (1992) reported that the global