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Plant diversity decreases net global warming potential integrating multiple functions in microcosms of constructed wetlands

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ABSTRACT

Constructed wetlands, which are designed ecosystems that consist of substrates, plants and microorganisms, have been used as an alternative clean technology to treat wastewater. However, greenhouse gas emission in constructed wetlands is still an accompanying problem. Finding a cleaner way to mitigate the net global warming potential while maintaining nitrogen removal efficiency has received increasing attention in recent years. High plant diversity has been found to increase nitrogen removal efficiency, but its effect on net global warming potential is not well understood. In this study, four species richness levels (1, 2, 3 and 4) were assembled in microcosms simulating constructed wetlands. The goal of this work is to explore the effects of plant diversity (species richness and identity) on the net global warming potential integrating multiple functions, including carbon sequestration in substrate, carbon dioxide emission mitigation by aboveground biomass converted to biofuel, and non-carbon dioxide (methane and nitrous oxide) emissions. Results showed that: (1) increasing species richness reduced the global warming potential based on carbon sequestration and carbon dioxide emission mitigation while increasing the global warming potential of non-carbon dioxide emissions of the microcosms; (2) increasing species richness mitigated the overall global warming potential due to the greater role of carbon sequestration and carbon dioxide emission mitigation; and (3) the presence of *Rumex japonicus* or *Oenanthe javanica* decreased the overall global warming potential of the microcosms. This study concluded that assembling communities with high plant species richness and several specific species instead of monocultures are more effective and cleaner for mitigating global warming potential while maintaining the efficiency of nitrogen removal.

1. Introduction

Wastewater production is increasing rapidly and threatening water and air quality, as well as human health (Schwarzenbach et al., 2010). The greenhouse gases emitted from wastewater treatment facilities are a considerable source of anthropogenic greenhouse gases (IPCC, 2014a). Globally, the greenhouse gas emissions from wastewater treatment plants (WTPs) have reached 775 Mt carbon dioxide (CO_2) equivalent (CO_2-eq) in the year 2010 (IPCC, 2014a) and will continue to increase in the future, along with the fast-growing population and rapid urbanization (Guisasola et al., 2008). Finding a cleaner and alternative wastewater treatment method that both mitigates the global warming potential (GWP) and maintains the pollutant removal efficiency has become an urgent challenge.

Constructed wetlands (CWs) are designed ecosystems that consist of substrates, plants, and microorganisms for treating wastewater effectively with low operation and maintenance costs

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(Wu et al., 2017). CWs have been reported as the clean and effective alternative to conventional wastewater treatment technology (Maucieri et al., 2017). The greenhouse gas emission intensities of CWs used for wastewater treatment per kg nitrogen (N) removal (0.9 kg CO_2-eq in average) are much lower than that of WTPs (592 kg CO_2-eq per kg N removal in average) (Liu et al., 2012). However, the total amount of greenhouse gas emissions from CWs will increase rapidly considering that the amount of wastewater will increase considerably (Mander et al., 2014). Novel approaches for a cleaner operation are needed for treating wastewater in CWs.

Plant diversity has been found to enhance ecosystem functioning in CWs. Some studies have reported that plant diversity can increase biomass production and carbon sequestration in substrate (Chang et al., 2014), which can also mitigate the greenhouse effect (Maucieri et al., 2016). However, plant diversity also found to increase methane (CH_4) (Zhang et al., 2012) and nitrous oxide (N_2O) emissions (Sun et al., 2013) of CWs. Furthermore, the carbon-related functioning in response to plant diversity has not been studied in detail, although CWs have been found to provide biofuel (Buller et al., 2013) by using nutrients contained in wastewater (Liu et al., 2012). The biofuel can replace fossil fuel consumption and subsequently reduce greenhouse gas emissions (Liu et al., 2012). Whether the effect of plant biodiversity on the net GWP that integrates multiple functions is positive or negative remains unexplored in CWs.

The goal of this work is to assess the effects of plant diversity (species richness and identity) on the GWP based on multiple functions in the microcosms that simulate CWs. This study tested: (1) the GWP mitigation by carbon sequestration in substrate and aboveground biomass converted to biofuel in response to species richness and identity; (2) the GWP of non-CO_2 greenhouse gas emissions (CH_4 plus N_2O) in response to plant species richness and identity; and (3) the GWP mitigation potential of integrating the above four functions in response to species richness and identity.

2. Methods

2.1. Experiment

The vertical subsurface-flow microcosms were established at the Zijingang campus (120° 05′ E, 30° 18′ N) of Zhejiang University, Hangzhou City, Southeast China. The microcosms that simulated CWs were filled with washed river sand. Four common water-tolerant and early-spring species, *Oenanthe javanica* (Bl.) DC., *Phalaris arundinacea* Linn, *Rumex japonicus* Houtt., and *Reineckia carnea* (Andr.) Kunth, were selected. The seedlings of the four species with similar in size and vigor were transplanted into the microcosms in March of 2011 (Fig. 1a and b). Based on the randomized block design (Hooper and Vitousek, 1998), 90 microcosms of varying plant species treatments (1, 2, 3, or 4 species per microcosm) were set up. Each block included one monoculture for each of the four species, six polycultures of two-species combinations, four polycultures of three-species combinations and one polyculture of a four-species combination. Each microcosm was planted with 12 individuals, with an equal number of individuals assigned to each species (i.e., 60 plants m^{-2}). The simulated wastewater is a modified Hoagland nutrient solution (Table 1), where the nitrate N is a unique N source (N concentration is 336 mg N L^{-1}) and the other elements are the same as in the original Hoagland nutrient solution. The solution ensures the normal growth and development of

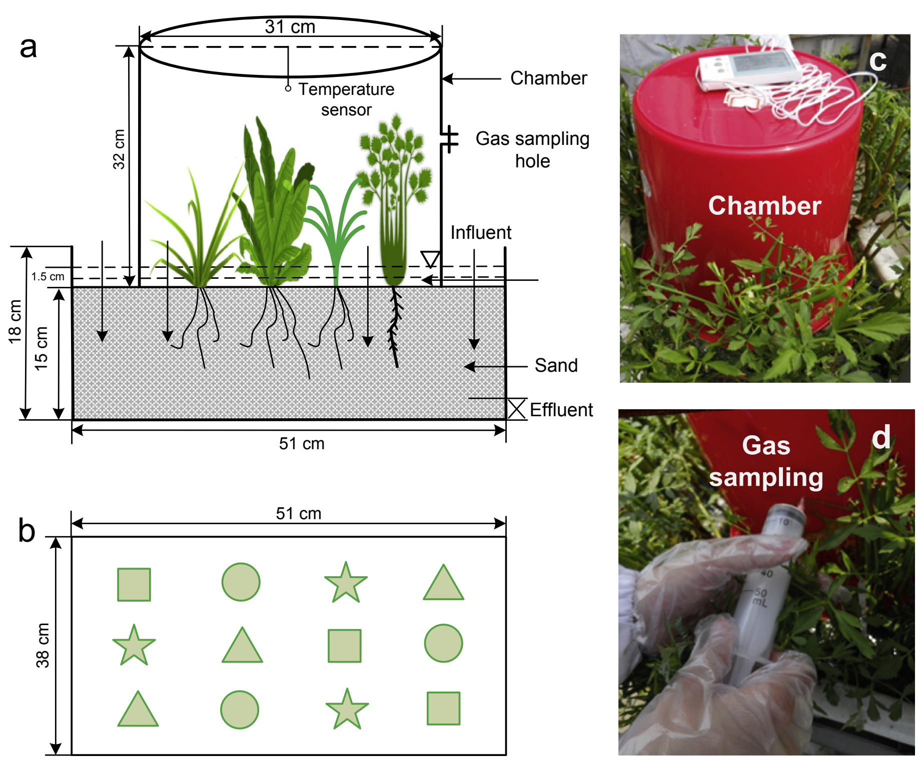

Fig. 1. Illustration of the microcosms of constructed wetlands: (a) The vertical cross-section of the microcosm (length × width × height = 51 × 38 × 18 cm) and the sampling chamber (cylindrical barrel with 24 L volume, the diameter is 31 cm and the height is 32 cm). (b) The top view of different plant configurations in a microcosm. The different shapes represent different plant species (12 plants per microcosm). (c) A picture of a gas chamber and the temperature and humidity measuring instrument (XC3101, Torex Company, Japan) located on top of the chamber. (d) A picture showing gas sampling using a syringe.