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Balancing carbon sequestration and GHG emissions in a constructed wetland

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ABSTRACT

In many countries wetlands are constructed or restored for removing nutrients from surface water. At the same time vegetated wetlands can act as carbon sinks when CO_2 is sequestered in biomass. However, it is well known that wetlands also produce substantial amounts of greenhouse gasses CH_4 and N_2O. Especially N_2O, resulting from nitrification and denitrification, is a very potent GHG. To assess the environmental sustainability of constructed wetlands the benefit of carbon sink and the downside of GHG emissions have to be evaluated. Since nutrient and carbon cycles in wetlands are complex and variable among wetlands and in time such a balance always contains uncertainties. Several studies have addressed this issue and indicated that CW can be either a sink or a source of CO_2 equivalents depending on the time scale of research and the environmental and management conditions involved. Here we balance carbon sequestration with CH_4 and N_2O emissions in a multi-functional constructed wetland, dominated by emergent *Phragmites* vegetation. Detailed measurements were combined with a nitrogen budget, and all fluxes were expressed as a range indicating the uncertainties in measurements and extrapolation techniques. Measured methane emissions were variable and showed clear relationship with temperature and density of the emergent vegetation. Average CH_4 emissions in the vegetation were 7.8 at 15 °C and 24.5 $\mathrm{mg\,m^{-2}\,h^{-1}}$ at 24 °C. Estimated N_2O emissions ranged from 0.5 to 1.9 $\mathrm{g\,m^{-2}\,y^{-1}}$. After converting the fluxes to CO_2 equivalents we concluded that the Lankheet constructed wetland is most likely a sink of CO_2 in the present conditions. Annual net sequestration of CO_2 amounts 0.27–2.4 $\mathrm{kg\,m^{-2}\,y^{-1}}$ which represents 12–67% of the CO_2 fixation in the biomass. N_2O emissions represent a substantial part of the total effect of GHG emissions (12–29%) and should not be disregarded in budget studies. We acknowledge the limitations and uncertainties of our estimates, however, we are confident that our findings contribute to assessing the environmental sustainability of constructed wetlands.

1. Introduction

Due to agricultural practices and human waste, many rivers and streams have gradually become polluted with nutrients (Billen et al., 1999; Boesch, 2002; de Klein et al., 2011) eventually causing eutrophication in downstream lakes and coastal waters (Bouraoui et al., 2011). To comply with the goals of the European Water Framework Directive (European Communities, 2005) the nutrient concentrations in most surface waters have to be reduced significantly. Constructed wetlands can be effective in removing nutrient from surface waters by accumulation in biomass and denitrification (Fisher et al., 2004; Vymazal, 2007). Besides nutrient removal constructed wetlands can serve other purposes like biomass production, hydraulic retention, biodiversity and nature development. Furthermore, constructed wetlands with emergent vegetation can sequester large amounts of carbon and therefore contribute to mitigation of climate change effects (Bridgham et al., 2006; Vymazal, 2011). The downside is that constructed wetlands can emit large quantities of greenhouse gasses (GHG) especially methane (CH_4) and nitrous oxide (N_2O) (Johansson et al., 2003; Sovik et al., 2006; Mander et al., 2008; Kayranli et al., 2010). In order to judge the environmental sustainability of constructed wetlands carbon sequestration and GHG emissions have to be balanced. However, the carbon and nitrogen cycles within wetlands are very dynamic and complex (Brix et al., 2001). Exchange of gasses with the atmosphere and fluxes within the wetland system do not only vary among wetlands, but also within a wetland large spatial and temporal variability is reported (Teiter et al., 2005; Hernandez et al., 2007; Thiere et al., 2011). This variability complicates an adequate quantification of the process rates and fluxes and introduces

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uncertainties in nutrient and carbon budgets of wetlands. Several studies have addressed this issue and indicated that constructed wetlands can be either a sink or a source of CO_2 equivalents depending on the time scale of research and the environmental and management conditions involved (Brix et al., 2001; Badiou et al., 2011; Thiere et al., 2011). Important factors determining the variability of GHG emissions are related to hydraulic conditions such as residence time and intermittent versus continuous loading (Altor and Mitsch, 2006; Mander et al., 2011). Moreover, differences in water temperature and available light are controlling seasonal variability of methane emissions from vegetated wetlands to a large extent (Kim et al., 1999; Brix et al., 2001; Kaki et al., 2001). Nitrous oxide exchanges with the atmosphere are variable and N_2O can be either emitted or taken up by wetlands (Johansson et al., 2003). Fluxes are often low and therefore difficult to quantify for field conditions.

In this research we study carbon and nitrogen fluxes in a multi-functional experimental wetland dominated by emergent *Phragmites* vegetation. The surface flow wetland, Lankheet, was constructed in 2005 by transforming 5 ha maize land on sandy soil into shallow ponds planted with reed. The purpose of the MFCW is nutrient removal from stream water, temporary water retention in periods of high rainfall, biomass production for green energy and nature conservation (Meerburg et al., 2010). From the start in 2005 the development and performance of the wetland is monitored intensively. The aim of this study is to compare carbon sequestration with emissions of CH_4 and N_2O to determine if the wetland is a source or sink of carbon, expressed in CO_2 equivalents (IPCC, 2007). Measurements of biomass and CH_4 emissions were combined with a nitrogen budget, from which denitrification and subsequently N_2O emissions were estimated. This approach might help to partly solve the problem of the variable N_2O measurements. All fluxes were expressed as a range indicating the uncertainties in measurements and extrapolation techniques.

2. Materials and methods

2.1. Approach

To be able to balance carbon sequestration and GHG emissions we measured biomass production in the *Phragmites* fields during 2009–2012. At the same time we measured and estimated N_2O and CH_4 gas emissions from the wetland. All rates were extrapolated to a whole year and expressed as CO_2 equivalents from which finally net sequestration was derived. To account for uncertainties we applied ranges for the fluxes (high-low).

Methane fluxes were measured in the wetland in May and June 2012. N_2O emissions were estimated from a nitrogen budget that was set up for the growing season 2009. For this period detailed data were available. Permanent losses of nitrogen in the wetland were attributed to denitrification of which a small part results in emission of N_2O to the atmosphere (Hernandez et al., 2007; Garcia-Lledo et al., 2011). To validate estimated N_2 and N_2O emissions denitrification was measured in situ during spring 2012.

2.2. Site description

The Lankheet experimental site was created in 2005 when a 5 ha maize field was converted into a constructed wetland separated into six fields, varying in surface area between 0.4 and 0.5 ha. Each field consists of three compartments. Water from the Buurserbeek lowland stream is pumped into the fields intermittently allowing a residence time of 2 days in the wetland. Inflow and outflow of stream water is monitored continuously with flow meters and flow-proportionate water samplers (Fig. 1). Each year above ground biomass and roots and rhizomes biomass were determined, as well as nutrients content of the wetland soils. A more detailed description of the area and experimental setup is reported by Meerburg et al. (2010).

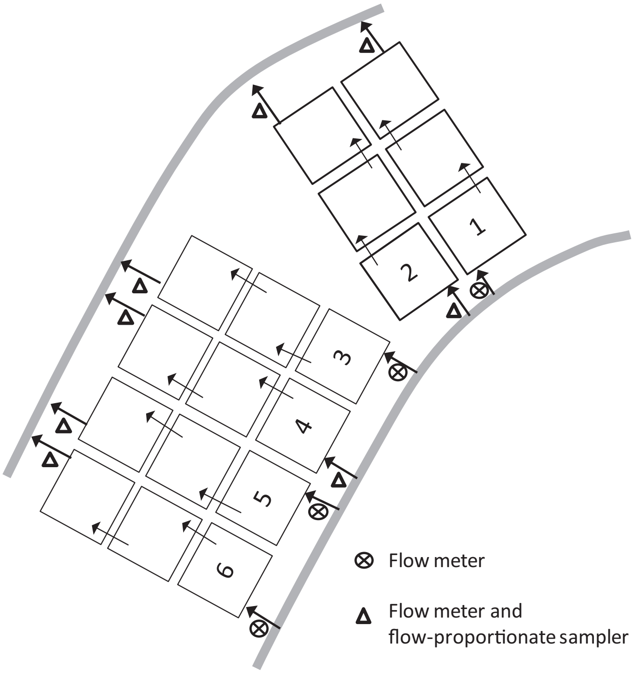

Fig. 1. Structure of the Lankheet constructed wetland. Six fields with separated flows, each consisting of three compartments. Circles and triangles represent locations of flow measurements and automatic water samplers.

2.3. Biomass production

Peak standing crop (kg d.w. ha^{-1}) was determined in September/October for the period 2009–2012, by sampling 0.5 m^2 ($n = 9$ per field, $n = 54$ for the whole system) (Meerburg et al., 2010). In 2009 aboveground biomass was also measured in May and July to study crop development during the growing season. In addition root and rhizome biomass was estimated in April and September 2009 using a root auger (diameter 10 cm) over a depth of 20 cm ($n = 9$ per field and $n = 54$ for the whole system). Deeper measurements revealed that very low belowground biomass was observed at depths below 20 cm. The biomass was oven dried at 70 °C for 48 h and total N content of the dry biomass was determined spectrophotometrically after destruction (Novozamsky et al., 1983).

Reed crop is typically harvested in winter time. We measured an average loss in peak above ground biomass of 22% (September to February, 2007/2008 and 2008/2009), which is supported by other research (Asaeda et al., 2006). The loss is mainly due to falling of the leaves, however part of this will be accumulated in the soil organic matter. Also a re-allocation from the shoots to the roots may be expected (Asaeda et al., 2006). Therefore, we estimated a net loss of 15% from the peak standing crop, so the remaining 85% was taken as annual productivity.

2.4. Nitrogen budget

A nitrogen budget was set up for the growing season (April–September) in the year 2009 using inflow and outflow of surface water, atmospheric deposition, accumulation in the soil,