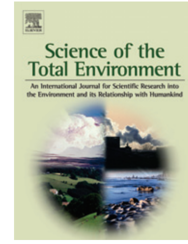
SCIENCE OF THE TOTAL ENVIRONMENT 404 (2008) 343–353

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/scitotenv



Gaseous fluxes in the nitrogen and carbon budgets of subsurface flow constructed wetlands

Ülo Mander[a,*], *Krista Lõhmus*[a,b], *Sille Teiter*[a], *Tõnu Mauring*[a,c], *Kaspar Nurk*[a], *Jürgen Augustin*[d]

[a]*Department of Geography, Institute of Ecology and Earth Sciences, University of Tartu, Vanemuise 46, Tartu, 51014, Estonia*
[b]*Department of Botany, Institute of Ecology and Earth Sciences, University of Tartu, Lai 40, Tartu, 51005, Estonia*
[c]*Institute of Technology, University of Tartu, Estonia*
[d]*Institute of Landscape Matter Dynamics, Leibniz-Centre for Agricultural Landscape Research (ZALF), Germany*

A R T I C L E I N F O

Available online 16 May 2008

Keywords:
Carbon budget
Carbon dioxide
Constructed wetlands
Dinitrogen
Global warming potential
Methane
Nitrogen budget
Nitrous oxide

A B S T R A C T

In 2001 and 2002, fluxes of N_2O, CH_4, CO_2 and N_2 were measured in two constructed wetlands (CW) for domestic wastewater treatment in Estonia. The difference between the median values of N_2O, CH_4, and N_2 fluxes in the horizontal subsurface flow (HSSF) CWs was non-significant, being 1.3–1.4 and 1.4–4.1 mg m^{-2} d^{-1} for N_2O–N and CH_4–C, and 0.16–0.17 g N m^{-2} d^{-1} for N_2–N respectively. The CO_2–C flux was significantly lower (0.6 g C m^{-2} d^{-1}) in one of the HSSF filters of a hybrid CW, whereas the single HSSF and VSSF filters emitted 1.7 and 2.0 g C m^{-2} d^{-1}. The median value of CH_4–C emission in CWs varied from 1.4 to 42.6 g C m^{-2} d^{-1}, being significantly higher in the VSSF filter beds. We also estimated C and N budgets in one of the HSSF CWs (312.5 m^2) for 2001 and 2002. The total C input into this system was similar in 2001 and 2002, 772 and 719 kg C $year^{-1}$, but was differently distributed between constituent fluxes. In 2001, the main input flux was soil and microbial accumulation (663 kg C $year^{-1}$ or 85.8% of total C input), followed by plant net primary production (NPP) (10.2%) and wastewater inflow (3.9%). In 2002, 55.7% of annual C input was bound in plant NPP, whereas the increase in soil C formed 28.5% and wastewater inflow 15.7%. The main C output flux was soil respiration, including microbial respiration from soil and litter, and the respiration of roots and rhizomes. It formed 120 (97.5%) and 230 kg C $year^{-1}$ (98.2%) in 2001 and 2002 respectively. The measured CH_4–C flux remained below 0.1% of total C output. The HSSF CW was generally found to be a strong C sink, and its annual C sequestration was 649 and 484 kg C $year^{-1}$ per wetland in 2001 and 2002 respectively. However, negative soil and microbial accumulation values in recent years indicate decreasing C sequestration. The average annual N removal from the system was 38–59 kg N $year^{-1}$ (46–48% of the initial total N loading). The most important flux of the N budget was N_2–N emission (22.7 kg in 2001 and 15.2 kg in 2002), followed by plant belowground assimilation (2.3 and 11.9 kg N $year^{-1}$ in 2001 and 2002), and above-ground assimilation (1.9 and 9.2 kg N $year^{-1}$, respectively). N_2O emission was low: 0.37–0.60 kg N $year^{-1}$.

1. Introduction

Both natural and constructed wetlands can be sources of three important greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O; Kadlec and Knight, 1996; Mitsch and Gosselink, 2000).

Relatively few studies have been carried out concerning N_2O and CH_4 fluxes from constructed wetlands (CW) for wastewater

* *Corresponding author*. Tel.: +372 55 40 579; fax: +372 73 66 676.
E-mail address: ulo.mander@ut.ee (Ü. Mander).

0048-9697/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.scitotenv.2008.03.014

treatment (Table 1). Most of the available data concern free water surface (FWS) CWs' contribution to N_2O (Xue et al., 1999; Wild et al., 2002; Johansson et al., 2003) and CH_4 (Tanner et al., 1997; Wild et al., 2002; Stadmark and Leonardson, 2005) emissions. Few studies (Fey et al., 1999; Mander et al., 2003; Liikanen et al., 2006; Mander et al., 2005b; Teiter and Mander, 2005) consider the N_2O fluxes from subsurface flow constructed wetlands (Table 1).

The emission of dinitrogen from wetlands is exclusively a product of denitrification (Knowles, 1982; Kadlec and Knight, 1996), although the ratio of N_2 to N_2O emission has only been analysed in a few studies (Watts and Seitzinger, 2000; Butterbach-Bahl et al., 2002; Teiter and Mander, 2005). The ratio of the released N_2O to N_2 tells us what amount of applied nitrogen fertilizers is being processed into harmful N_2O and how much is transformed into harmless N_2 (Mosier, 1998). As in agricultural systems, in CWs the ratio characterizes the quality of the denitrification process. This is generally referred to as the microbial reduction of NO_3^-–N to NO_2^-–N and further to gaseous forms NO, N_2O and N_2 (Knowles, 1982), and it has been found in numerous studies to be a significant process in nitrogen removal in CWs (Kadlec and Knight, 1996; Bachand and Horne, 2000; Lund et al., 2000) and in various buffering ecosystems in rural areas (Groffman et al., 1991; Hefting and de Klein, 1998; Hefting et al., 2003). However, only very few papers analyse N_2 emissions from CWs (Fey et al., 1999; Mander et al., 2003; Teiter and Mander, 2005).

Both denitrification and methane formation depend on the oxygen status of the soil or sediment. As a result, the spatial and temporal variability of fluxes of both N_2O (Robertson and Tiedje, 1984; Augustin et al., 1998b;) and CH_4 (Saarnio et al., 1997; Willison et al., 1998) are extremely high. Denitrification rates in soils are also influenced by carbon availability, nitrate availability, temperature, detention time, and pH (Mitsch and Gosselink, 2000). CH_4 is produced in anoxic soils and sediments, while well-drained soils act as a sink for atmospheric CH_4 due to methane oxidation, through either ammonia oxidizers or methanotrophs (Hanson and Hanson, 1996).

Numerous studies consider emissions and the sequestration of carbon dioxide (CO_2) in wetlands (Raich and Schlesinger, 1992; Franzen, 1994; Mitsch and Gosselink, 2000; Turetsky et al., 2002; Zhang et al., 2005). Depending on the meteorological and hydrological conditions, wetlands can be either sources or sinks of carbon (Carroll and Crill, 1997; Whiting and Chanton, 2001). A limited number of studies consider CO_2 fluxes from CWs (Mander et al., 2005a,b; Liikanen et al., 2006).

The carbon balance has been estimated for several natural wetlands worldwide (Mitsch and Gosselink, 2000), and the majority of wetlands studied are located in boreal and arctic regions (Shaver et al., 1992; Aurela et al., 2002; Mack et al., 2004), which possess about one third of global C stocks (Shaver et al., 2000) and are critical to the process of global warming (Carroll and Crill, 1997; Waddington and Roulet, 2000; Clair et al., 2002; Heikkinen et al., 2004). In comparison, only limited studies have been performed on the carbon balance in CWs (Meuleman et al., 2003). Investigations on nitrogen budgets have been carried out in different types of natural wetlands (Verhoeven and Schmitz, 1991; Devito and Dillon, 1993; Mitsch and Gosselink, 2000) as well as CWs (Lund, 1999; Gerke et al.,

Table 1 – Emission of nitrous oxide and methane in constructed wetlands for wastewater treatment

References	Country	Type of constructed wetland and wastewater	N_2O flux (mg N_2O–N m^{-2} h^{-1})	CH_4 flux (mg CH_4–C m^{-2} h^{-1})	Initial load g m^{-2} d^{-1}	N_2O % of N input	Comments
Tanner et al. (1997)	New Zealand	FWSW; dairy farm wastewater (*Schoenoplectus validus*)	–	27.6...278	BOD: 20...35	–	Range of median values
Augustin et al. (1998a)	Germany	Minerotrophic fens	1.4...3.8	−0.6...9.0	–	–	Range
Fey et al. (1999)	Germany	HSSF planted soil filter (*Phragmites australis*)	3.2	–	BOD: 1.7	0.008	Average value
Xue et al. (1999)	USA	FWSW agricultural tile drainage water	0.3...2.9	–	N: 0.15...0.20	0.19...1.4	Range
Tai et al. (2002)	PR China	FWSW raw municipal wastewater	–	130	BOD: 15...20	–	Average value
Wild et al. (2002)	Germany	FWSW agric. drainage water (*Typha spp.*)	−0.2...1.9	−1.0...35.3	N: 0.18 0.36	−0.14...0.52	Range
Johansson et al. (2003)	Sweden	Macrophyte ponds with:					
		Glyceria maxima	1.2±1.6				Median±SD values
		Typha latifolia	3.8±6.4				for N_2O–N emission
		Phalaris arundinacea	6.0±5.4				
		Spirogyra spp	1.5±2.0				Median value for CH_4–C
		Lemna minor	2.3±1.8				emission
		Without plants	6.0±4.2				
		Whole system	3.1±5.3	2.0±3.0	N: 0.21	1.5	
Mander et al. (2005a,b)	Estonia	HSSF planted soil filter (*Scirpus sylvaticus, P australis*)	0.2...17.0	1.7...528	N: 0.38...0.45 BOD: 0.41...0.45	0.06...3.8	Range of mean values
Mander et al. (2005a,b)	Estonia	VSSF planted soil filter (*P. australis*)	11.0	16.4	N: 3.8 BOD: 25	0.29	Average values