Soil Biology & Biochemistry 68 (2014) 291–299

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Nitrous oxide fluxes in undisturbed riparian wetlands located in agricultural catchments: Emission, uptake and controlling factors

Joachim Audet [a,*], Carl C. Hoffmann [a], Peter M. Andersen [a], Annette Baattrup-Pedersen [a], Jan R. Johansen [a], Søren E. Larsen [a], Charlotte Kjaergaard [b], Lars Elsgaard [b]

[a] Aarhus University, Department of Bioscience, Vejlsøvej 25, 8600 Silkeborg, Denmark
[b] Aarhus University, Department of Agroecology, P.O. Box 50, Blichers Allé 20, 8830 Tjele, Denmark

ARTICLE INFO

Article history:
Received 24 June 2013
Received in revised form
16 August 2013
Accepted 7 October 2013
Available online 22 October 2013

Keywords:
Riparian wetlands
Greenhouse gas
Nitrous oxide
Sink
Source
Uptake

ABSTRACT

Riparian wetlands can mitigate nutrient pollution to the aquatic environment when they serve as biogeochemically active buffer zones between arable land and water bodies. Nevertheless, as a result of the extensive nutrient transformation, wetlands hold a potential of atmospheric emission of greenhouse gases such as nitrous oxide (N_2O). To quantify this potential, fluxes of N_2O were measured over a year at 48 sub-plots located in four Danish riparian wetlands with contrasting characteristics of soil parameters and groundwater dynamics. The wetlands were hydrologically and physically relatively undisturbed, but they were all located in catchments dominated by agriculture. Individual fluxes of N_2O measured using the static chamber technique ranged from −44 to 122 μg N_2O–N m^{-2} h^{-1} ($n = 800$) while cumulative fluxes ranged from −0.25 to 0.50 g N_2O–N m^{-2} yr^{-1} ($n = 48$), i.e., showing both uptake and emission of N_2O. Modeling of the fluxes using linear mixed models revealed that ammonium in the groundwater was the only tested variable having a significant effect on N_2O fluxes. Tentative maximum estimates showed that only about 2.2% of the total Danish N_2O emissions could be related to freshwater wetlands (representing about 1.3% of the land area). Further, the low and frequently negative N_2O fluxes ($n = 294$) indicated that riparian wetlands, at least under some conditions, may actually reduce atmospheric N_2O pollution, although the measured N_2O uptake was weak. In conclusion, riparian ecosystems with only minor disturbances are not generally to be considered as hotspots of N_2O emissions in the landscape.

1. Introduction

Riparian wetlands are situated at the interface between terrestrial and aquatic ecosystems. In their natural state, such wetlands generally have a high biodiversity and serve as floodwater storage and filter for waterborne pollutants (de Groot et al., 2002). Wetlands can also sequester carbon (C) as photosynthetic plant uptake of carbon dioxide (CO_2) often exceeds ecosystem respiration under water-saturated soil conditions (Reddy and DeLaune, 2008). The overall contribution of wetlands to climate change is still a matter of debate, though, as wetlands can also produce greenhouse gases (GHG), and they are the largest natural emitter of methane (CH_4; IPCC, 2007). Hence, while some studies suggest that wetlands are net sources of GHG because of CH_4 emissions (Bridgham et al., 2006), other reports argue that over a long time horizon (>100 yrs) wetlands can be considered as sinks for GHG (Mitsch et al., 2012; Whiting and Chanton, 2001). For example, in a modeling study (Mitsch et al., 2012) showed that over a time horizon of >300 yrs most wetlands are net C sinks because CH_4 emissions are compensated by C sequestration in the soil.

In addition to the exchange of CO_2 and CH_4, riparian soil may also contribute to fluxes of nitrous oxide (N_2O). In water-saturated soils, it is assumed that the main N_2O-producing process is denitrification, which is the reduction of nitrate (NO_3^-) and nitrite (NO_2^-) to the gaseous end products N_2O or dinitrogen (N_2) (Tiedje, 1982). Although the fraction of produced N_2O might be small (Groffman et al., 1998), it may have important consequences for atmospheric pollution because N_2O is a potent GHG with a global warming potential 298 times as strong as CO_2 over a 100 yrs time horizon (IPCC, 2007). The capacity of wetland soils to transform aqueous N to gaseous N has been exploited within the context of wetland restoration where efficiency in mitigating aquatic N pollution has been documented (Hoffmann and Baattrup-Pedersen, 2007; Hoffmann et al., 2011). Yet, some studies have expressed concerns about

* Corresponding author. Tel.: +45 871 585 62; fax: +45 871 58 901.
E-mail addresses: joau@dmu.dk (J. Audet), cch@dmu.dk (C.C. Hoffmann), petermejlhede@gmail.com (P.M. Andersen), abp@dmu.dk (A. Baattrup-Pedersen), jan.ravn@hotmail.dk (J.R. Johansen), sel@dmu.dk (S.E. Larsen), C.Kjaergaard@agrsci.dk (C. Kjaergaard), Lars.Elsgaard@agrsci.dk (L. Elsgaard).

0038-0717/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.soilbio.2013.10.011

Table 1
Soil characteristics (top soil, 0–30 cm) and dominant vegetation at the study sites.

Wetland	Plot	Soil type (0–30 cm)	Soil pH	Bulk density (g cm^{-3})	TN (% DW)	N In top soil (g cm^{-2})	C/N ratio (mol mol^{-1})	Dominant vegetation (% of plant cover indicated in parentheses)
Karup	P1	Fibric peat	6.6	0.12	1.20	0.043	20.4	*Calliergonella cuspidata* (45), *Lotus pedunculatus* (20), *Festuca rubra* (9)
	P2	Hemist peat	6.7	0.29	0.80	0.070	20.4	*Menyanthes trifoliata* (49), *Carex nigra* (22), *C. cuspidata* (15)
	P3	Hemist peat	6.8	0.53	0.39	0.062	18.8	*Comarum palustre* (36), *Glyceria maxima* (20), *Cirsium palustre* (16)
Haderup	P1	Hemist peat	6.3	0.10	2.40	0.072	21.4	*M. trifoliata* (32), *C. cuspidata* (26), *F. rubra* (12)
	P2	Hemist peat	6.3	0.30	0.79	0.071	20.7	*Filipendula ulmaria* (29), *Equisetum fluviatile* (25), *L. pedunculatus* (22)
	P3	Sapric peat	7.0	0.14	1.30	0.055	21.5	*Lysimachia vulgaris* (47), *C. cuspidata* (22), *C. palustre* (19)
Simested	P1	Sapric peat	6.3	0.36	0.46	0.050	15.7	*G. maxima* (79), *Epilobium hirsutum* (11), *Equisetum palustre* (5)
	P2	Fibric peat	6.5	0.04	2.30	0.028	22.8	*C. cuspidata* (27), *F. rubra* (25), *M. trifoliata* (9)
	P3	Hemist peat	5.8	0.23	1.70	0.117	16.5	*F. rubra* (25), *C. nigra* (24), *C. cuspidata* (23)
Villestrup	P1	Fibric peat	5.5	0.17	1.50	0.077	18.7	*Lychnis flos-cuculi* (16), *Carex disticha* (10), *Agrostis stolonifera* (9)
	P2	Fine sand	4.7	1.25	0.16	0.060	15.3	*Deschampsia flexuosa* (36), *Ranunculus repens* (26), *F. rubra* (12)
	P3	Fine sand	4.8	1.10	0.28	0.092	15.8	*Holcus mollis* (28), *R. repens* (21), *D. flexuosa* (20)

DW, dry weigh.

diverting N rich waters toward wetlands because of the risk of increased N_2O emissions (Freeman et al., 1997; Groffman et al., 2000; Verhoeven et al., 2006; Bouwman et al., 2013; Hefting et al., 2013). This risk is especially present in catchments having high proportion of agricultural land use because their groundwaters are often contaminated by NO_3^- derived from fertilizers (Smith et al., 1999; Moss, 2008).

Existing studies from natural riparian wetlands have generally shown high spatial and temporal variability in N_2O fluxes (Hefting et al., 2006; Jacinthe et al., 2012; Jørgensen et al., 2012); some riparian soils act as sources of N_2O (e.g., Walker et al., 2002; Hefting et al., 2003) and others as N_2O sinks (Blicher-Mathiesen and Hoffmann, 1999; Dhondt et al., 2004). Parameters such as NO_3^- load, oxygen content and pH are known to influence N_2O production (Reddy and DeLaune, 2008), but the dynamic interactions between the factors responsible for the production and emission of N_2O in the field are still difficult to incorporate into predictive models (Groffman et al., 2000; Baggs, 2008; Morse et al., 2012; Butterbach-Bahl et al., 2013).

To provide some insights into the N_2O dynamics in natural riparian wetlands we measured N_2O emissions over a year in four temperate riparian wetlands that were located in agricultural catchments but had relatively well preserved physical conditions (i.e., naturally meandering streams and absence of drainage in the wetland). We aimed at quantifying the seasonal and spatial dynamics of the fluxes of N_2O and at identifying the controllers of these fluxes using a modeling approach.

We hypothesized that N_2O emission from such riparian wetlands could be substantial at least under certain environmental conditions because these ecosystems are located in agricultural catchment and hence may receive high loads of NO_3^-. The study therefore targeted undisturbed wetlands located in contrasting areas and showing different characteristics in terms of, e.g., groundwater chemistry, groundwater level and soil properties, such as pH and mineral N content.

2. Materials and methods

2.1. Study sites

The riparian wetlands were located along four naturally meandering streams, representing some of the least disturbed streams in Denmark (Baattrup-Pedersen et al., 2013). One site was located along River Karup (N 56.417°, E 9.002°), one along River Haderup (N 56.404°, E 9.009°), one along River Simested (N 56.687°, E 9.484°) and one along River Villestrup (N 56.739°, E 9.958°). Agriculture was the dominant land use representing 61% (Karup), 51% (Haderup), 82% (Simested) and 46% (Villestrup) of the river catchment area.

In each riparian wetland, three plots (P1, P2 and P3) having an area of ca. 25 m^2 were selected based on differences in plant community types (Audet et al., 2013b) that we used as a way to capture environmental variability. All plots were located within 100 m from the stream channel. Although most of the plots may occasionally be flooded in periods with high discharges, no inundations by stream water occurred during the study period (June 2010–July 2011). However, some plots were inundated because of high groundwater level. Annual precipitation during the study period at the sites ranged between 688 and 831 mm and the mean temperature was 7.6 °C. Each plot comprised four sub-plots (55 × 55 cm) that were established in order to cover spatial heterogeneities.

The main characteristics of the plots regarding soil and vegetation characteristics are presented in Table 1, and a more detailed description of the plots and sub-plots is given in Audet et al. (2013b). The vegetation at Karup and at Haderup was not managed, whereas the study sites at Simested and Villestrup were grazed by cattle. Mineral fertilizer (200 kg N ha^{-1}) was applied to the study site at Villestrup every year, including areas near the three study plots. At all study sites, the vegetation inside the plots was neither mowed nor grazed during the study period.

2.2. Soil characteristics and mineral N

At each plot, undisturbed volumetric soil cores (5 cm diam., $n = 2$) were collected at 0–30 cm depth with a liner sampler (04.15.SB, Eijkelkamp, NL) within a distance of ca. 5 m from the sub-plots. Soil pH was determined in the field directly in the wet soil cores using a field pH meter (HACH HQ11d) and a field electrode (Radiometer pH C2051-8). Soil bulk density was measured after drying one of the cores at 105 °C. The second core was oven dried at 60 °C and ground-milled before determination of soil C and N contents by dry combustion (elemental analysis) at AGROLAB GmbH, Germany, using international standards (ISO 10694, 1995; ISO 13878, 1998). The top soil (0–30 cm) content of total N was calculated as: N content (g g^{-1}) × bulk density (g cm^{-3}) × 30 (cm).

The mineral N content of the soil was determined on three occasions (March, May and June 2011) by randomly taking five individual cores (3.5 cm diam., 30 cm length) at every plot. The cores were pooled and stored in the dark at 2 °C before further processing (within one week). The soil samples were thoroughly mixed and visible roots and stones removed. Duplicate samples of 10 g soil were extracted with 1 M KCl at a soil:KCl ratio of 1:4 (wt:wt) by shaking end-over-end for 60 min. The samples were then centrifuged (1000 rpm, 5 min) and the extracts filtered through Whatman GF/C glass fiber filters. The filtrates were collected and stored at 2 °C prior to colorimetric analysis for NH_4^+ (DS/EN ISO 11905,