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Nitrous oxide emissions from streams in a Swedish agricultural catchment

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ABSTRACT

Excess nitrogen fertiliser in agricultural soils might be leached to streams and converted to the greenhouse gas nitrous oxide (N_2O). To assess the importance of N_2O emissions from agricultural streams, concentration dynamics and emissions N_2O emissions in streams were investigated in a 32 km^2 lowland agricultural catchment located in Sweden. Dissolved N_2O concentration was measured at nine occasions between December 2014 and August 2015 at nine stream stations. The stream stations represented sub-catchments with different land use characteristics with agricultural land use ranging from 0 to 63% of the area. Stream N_2O percentage saturation ranged 40–2701% and showed large spatial and temporal variations. Statistical analysis using mixed models revealed that N_2O concentration was significantly linked to nitrate concentration in the stream water, to the percentage arable land in the sub-catchments as well as to the stream water discharge. Using two empirical equations to estimate the N_2O emissions showed that streams were generally a source of N_2O to the atmosphere (mean 108 and 175 $\mu g\,N\,m^{-2}\,h^{-1}$ with first and second equation). The catchment scale estimate of N_2O stream emissions was compared to the estimate obtained using IPCC guidelines linking N fertilisation inputs and leaching to N_2O emissions. The comparison suggested that N_2O stream emission calculated using the IPCC methodology might be underestimated. A coarse estimate suggests that N_2O stream emissions represent about 4% of the total N_2O emissions from N-fertiliser at the catchment scale. Hence while streams covered only 0.1% of the catchment area they were of disproportionate importance as a source of N_2O to the atmosphere.

1. Introduction

Over recent decades, the use of fertilisers to improve agricultural yields has dramatically increased worldwide and will probably continue to increase to help feed the growing global population (Vitousek et al., 1997; Galloway et al., 2004; Fowler et al., 2013). However, a fraction of nitrogen (N) fertilisers applied on fields is not used by crops and is leached to groundwater, streams, lakes and further downstream (Fowler et al., 2013). During transport, N can undergo several transformations that produce nitrous oxide (N_2O) an ozone-depleting substance and a greenhouse gas 298 times more potent than carbon dioxide (CO_2) over a 100-year time scale (Myhre et al., 2013).

Nitrous oxide is produced naturally in soils, sediments and in aquatic vegetation by two main microbial processes, nitrification and denitrification (Butterbach-Bahl et al., 2013). Nitrification converts ammonia (NH_3) or ammonium (NH_4^+) into nitrate (NO_3^-) whereas denitrification transforms NO_3^- to dinitrogen gas (N_2). However, during these processes a fraction of the N may be released as N_2O. This fraction is generally low in the range 0–1% but can be much higher, especially during denitrification when environmental conditions (e.g., high NO_3^- concentration and low pH) impede the conversion from N_2O into N_2 (Groffman et al., 2000; Baggs and Philippot, 2011).

According to the International Panel on Climate Change (IPCC), two of the main anthropogenic sources of N_2O are agriculture (soil emissions and animal production; 4.1 Tg $N\text{-}N_2O\,yr^{-1}$) and freshwater aquatic ecosystems (0.6 Tg $N\text{-}N_2O\,yr^{-1}$). These two sources contribute to about 68% of the total N_2O anthropogenic emissions (Ciais et al., 2014). But while agricultural soils have been

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extensively studied (e.g. Mosier et al., 1998; Smith et al., 2008; Reay et al., 2012; Rees et al., 2013), the importance of fresh waters, in particular streams as a source of N_2O in the landscape has received less attention (Baulch et al., 2011; Hu et al., 2016).

Streams are likely an important source of atmospheric N_2O, especially in agricultural areas since they often receive high N load, mainly from leaching of fertiliser-derived N. For example, based on a study of 72 streams located in the U.S., Beaulieu et al. (2011) estimated that stream and river systems may contribute up to 10% of the global anthropogenic N_2O emissions which is three times the estimate from the IPCC (Ciais et al., 2014). Hence, underestimated N_2O emissions from streams might partially explain the discrepancy between top-down and bottom-up N_2O emission inventories (Griffis et al., 2013; Chen et al., 2016). Recent studies have confirmed that the IPCC guidelines for national gas inventories might underestimate riverine N_2O loss (Outram and Hiscock, 2012; Turner et al., 2015). These results contrast with the 2006 change in the IPCC guidelines that reduced the emission factor for riverine N_2O loss (EF_{5r}) from 0.015 to 0.0025 (IPCC, 2006). Nevertheless, there is a general agreement that N_2O emission from streams is significant and has an impact on atmospheric pollution (e.g. Baulch et al., 2011; Beaulieu et al., 2011; Outram and Hiscock, 2012; IPCC, 2013; Turner et al., 2015). Still, existing estimates of N_2O emissions from streams remain poorly constrained and factors controlling N_2O production and emission needs to be better characterised, particularly for lowland streams that are typical in agricultural landscapes.

In this study, we measured dissolved N_2O concentration in headwater streams in a Swedish agricultural catchment. Our aim was to investigate the environmental variables explaining the spatial and temporal variability of N_2O concentration in these streams. Specifically, we hypothesized that streams in sub-catchments with a greater intensity of agriculture fertiliser have higher N_2O concentrations. Finally we estimated the total riverine N_2O emission at the catchment scale and compared our estimate to riverine N_2O emission calculated following IPCC guidelines.

2. Material and methods

2.1. Study site

The study was conducted in an agricultural catchment (32 km^2) located ca 40 km west of Uppsala, Sweden (Fig. 1). The dominant soil texture in the catchment is loamy clay, elevation in the catchment ranges between 10 and 58 m above sea level, average yearly precipitation is 623 mm and average temperature is 5.5 °C (Kyllmar et al., 2014). Arable land comprises 61% of the land use while forest covers 31%. The crop production consists mostly of cereals (e.g. barley, wheat) and the livestock density is very low (< 0.1 animal units ha^{-1}). Few households are present and the population density is about 10 people km^{-2}. The catchment is part of the Swedish Agricultural Monitoring Programme which includes water chemistry sampling at the stream outlet, continuous water flow measurements and crop management surveys since 1993 (catchment C6, (Kyllmar et al., 2006, 2014)). Nine stream sampling stations were selected within the catchment. The outlet of the catchment at station 1 is a third-order stream (Strahler) and the streams in the catchment usually do not exceed 2 m width at bankfull discharge. Most of the streams in the catchment have been channelized, are deeply incised and receive water from tile drainage of the neighbouring fields. Some of the smaller streams may dry out in the summer during dry years although it was not the case during the study period. The stream slope at the stations ranged from 0.22-8.58 mm m^{-1} (Table 1). The stream at station 9 might occasionally receive N contaminated water pumped out from a quarry located in an adjacent catchment. The sub-catchments draining each of the sampling stations were identified from a high resolution digital elevation model (2 m resolution;

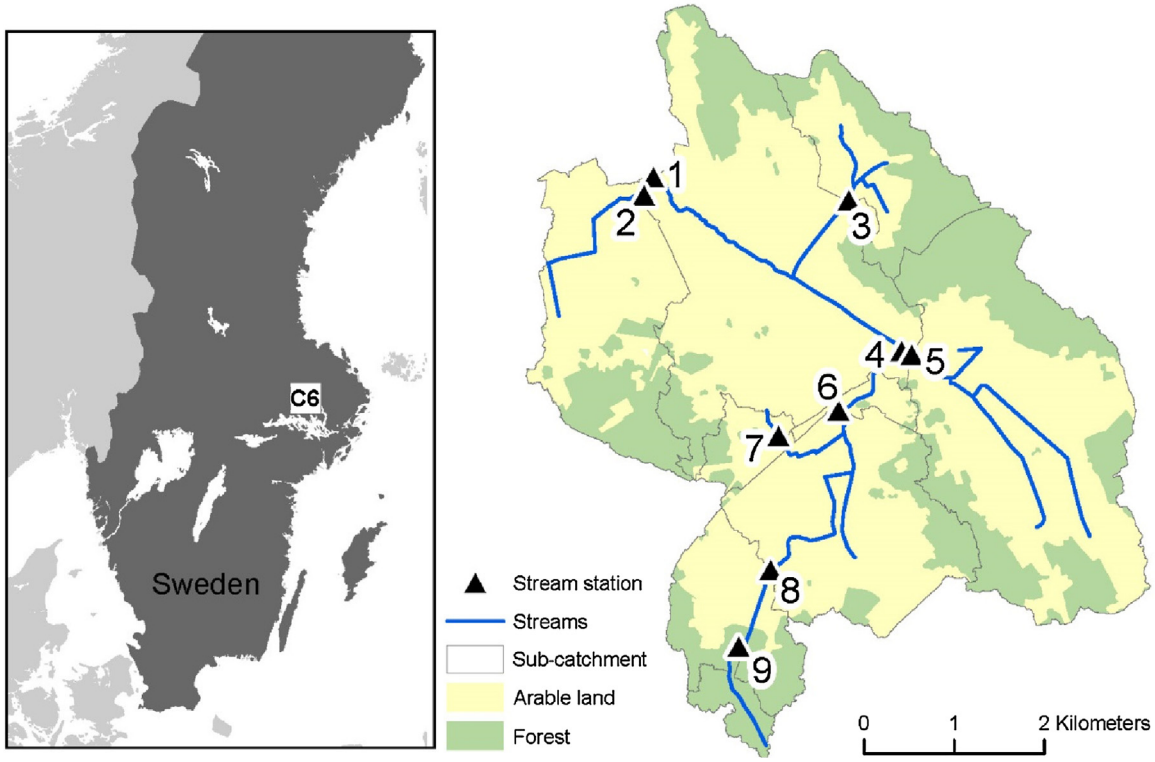

Fig. 1. Map of Sweden and of the studied catchment C6. The catchment is located within the 50 × 50 km square. The numbered black triangles show the location of the nine stream stations. Water discharge was measured at the outlet of the catchment at Station 1.