Environmental Pollution 242 (2018) 480–491

Contents lists available at ScienceDirect

Environmental Pollution

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

Indirect N_2O emissions with seasonal variations from an agricultural drainage ditch mainly receiving interflow water☆

Linlin Tian [a, b, c, d], Hiroko Akiyama [d], Bo Zhu [a, b, *], Xi Shen [a, b]

[a] Key Laboratory of Mountain Surface Processes and Ecological Regulation, Chinese Academy of Sciences, Chengdu 610041, China
[b] Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu 610041, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization, Tsukuba 305-8604, Japan

ARTICLE INFO

Article history:
Received 26 January 2018
Received in revised form
3 July 2018
Accepted 4 July 2018
Available online 7 July 2018

Keywords:
Nitrous oxide (N_2O)
Indirect N_2O emission factor (EF_{5g})
Intensive precipitation
Nitrate
Leaching
Drainage ditch

ABSTRACT

Nitrogen (N)-enriched leaching water may act as a source of indirect N_2O emission when it is discharged to agricultural drainage ditches. In this study, indirect N_2O emissions from an agricultural drainage ditch mainly receiving interflow water were measured using the static chamber-gas chromatography technique during 2012–2015 in the central Sichuan Basin in southwestern China. We found the drainage ditch was a source of indirect N_2O emissions contributing an inter-annual mean flux of 6.56 ± 1.12 μg N m^{-2} h^{-1} and a mean indirect N_2O emission factor (EF_{5g}) value of $0.03 \pm 0.003\%$. The mean EF_{5g} value from literature review was 0.51%, which was higher than the default EF_{5g} value (0.25%) proposed by the Intergovernmental Panel on Climate Change (IPCC) in 2006. Our study demonstrated that, more *in situ* observations of N_2O emissions as regards N leaching are required, to account for the large variation in EF_{5g} values and to improve the accuracy and confidence of the default EF_{5g} value. Indirect N_2O emissions varied with season, higher emissions occurred in summer and autumn. These seasonal variations were related to drainage water NO_3^--N concentration, temperature, and precipitation. Our results showed that intensive precipitation increased NO_3^--N concentrations and N_2O emissions, and when combined with warmer water temperatures, these may have increased the denitrification rate that led to the higher summer and autumn N_2O emissions in the studied agricultural drainage ditch.

1. Introduction

Atmospheric concentrations of the ozone-depleting, and potent greenhouse gas nitrous oxide (N_2O), have increased from a pre-industrial level of 270 ppb–324 ppb in 2011. One of the main causes of this rise in atmospheric N_2O is the increasing use of nitrogen (N) fertilizers (Ravishankara et al., 2009; IPCC, 2013). Considerable amounts of N are lost from N-fertilized agricultural land via leaching and runoff, and which is ultimately transported into groundwater, drainage ditches, rivers and estuaries, consequently causing N pollution in aquatic ecosystems (Mosier et al., 1998; Mulholland et al., 2008; Zhu et al., 2009; Gumiero et al., 2011). There have been several reports of groundwater contaminated with high nitrate (NO_3^-) concentrations in areas of high fertilizer use (Groffman et al., 1998; McMahon et al., 2000; Hiscock et al., 2003; Jahangir et al., 2013). In addition to studies on direct emissions of N_2O from N fertilized soils, indirect N_2O emissions from aquatic ecosystems that are associated with N leaching and runoff in agricultural areas deserve attention (Nevison, 2000; Beaulieu et al., 2008; Outram and Hiscock, 2012; Tian et al., 2017). The N-enriched groundwater associated with N leaching is considered a source of indirect N_2O emissions via denitrification or degassing when it is discharged to adjacent watercourses such as drainage ditches and streams (McMahon et al., 2000; Reay et al., 2004a, 2004b; Minamikawa et al., 2011; Jurado et al., 2017). Werner et al. (2012), for example, found that agricultural streams were a significant source of N_2O, while Jurado et al. (2017) also found that groundwater could act as a source of N_2O to the atmosphere and with the highest level of N_2O flux in springs supplied by groundwater compared with those in wetland and estuarine areas. Reay et al. (2004a and 2004b) reported that concentrations of dissolved N_2O

☆ This paper has been recommended for acceptance by Dr. Harmon Sarah Michele.

* Corresponding author. Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, No. 9, Block 4, Renminnanlu Road, Chengdu 610041, China.
E-mail address: bzhu@imde.ac.cn (B. Zhu).

https://doi.org/10.1016/j.envpol.2018.07.018
0269-7491/© 2018 Published by Elsevier Ltd.

in leachate rapidly decreased on entry to drainage ditches.

Drainage ditches in farmlands are generally ubiquitous and, as such, represent important hydrologic conduits for surface and subsurface N flow to aquatic systems (Kröeger et al., 2007; Shen et al., 2016; Zhu et al., 2012). Many drainage ditches are polluted and suffer from eutrophication, owing to losses of N from agriculture (Janse and Van Puijenbroek, 1998). But drainage ditches also act as important sites for biogeochemical interactions between reactive N, aquatic plants, microorganisms, and the physical environment (Janse and Van Puijenbroek, 1998; Shen et al., 2016; Zhang et al., 2016). Consequently, drainage ditches have been identified as hotspots for N removal and N_2O emissions (Reay et al., 2003, 2004a; Kröeger et al., 2007; Zhang et al., 2016). It is possible that spatial and temporal variations in N_2O emissions can be caused by dynamic changes in drainage water NO_3^- concentrations and other geochemical and hydrological parameters (Beaulieu et al., 2009; Jurado et al., 2017; Tian et al., 2017). It has thus been suggested that these variations should be considered in improving the certainty of quantification of indirect N_2O emissions (Werner et al., 2012; Jurado et al., 2017).

The Intergovernmental Panel on Climate Change (IPCC) has defined the emission factor for indirect N_2O emissions from leaching and runoff from agricultural systems as EF_5. This EF_5 incorporates three components: EF_{5g}, EF_{5r} and EF_{5e}, which are the emission factors for groundwater and surface drainage, rivers, and estuaries, respectively (IPCC, 2006). The default value of the EF_5 was defined as the proportion of N leaching and runoff converted to N_2O in these water bodies (IPCC, 2006). However, the default value proposed by the IPCC to estimate N_2O emissions in drainage ditches and groundwater resulting from leached N has a lack of certainty (Clough et al., 2007a; Beaulieu et al., 2008; Outram and Hiscock, 2012; Jahangir et al., 2013), since it has decreased from 2.5% in 1997 to 0.25% in 2006, based on studies from a limited number of countries (IPCC, 2006; Outram and Hiscock, 2012). In view of the large variation (0.002%–73%) in the values of EF_{5g} (Jurado et al., 2017), the default value requires improvement by increasing the number of global *in situ* observations (Reay et al., 2003; Beaulieu et al., 2008; Outram and Hiscock, 2012).

In China, the sloping farmland of the purple soils in the central Sichuan Basin is particularly vulnerable to N loss via NO_3^--N leaching due to a combination of intensive farming practices, hilly topography, climate, and soil characteristics (Zhu et al., 2009; Wang and Zhu, 2011; Gao et al., 2014), where the annual loss of N from these soils via interflow was reported to be 37.9 kg ha^{-1}, and accounted for 88% of the total N loss (Zhu et al., 2009). Interflow is the lateral movement of water in the unsaturated zone, that returns to the surface or enters a stream prior to becoming groundwater. Interflow was reported as an important water flow pattern in this area (Zhao et al., 2013), where the main N loss pathway from the local farmland is NO_3^--N leaching via interflow (Wang and Zhu, 2011). Previous studies have also reported that interflow was the predominant pathway of water discharge (Zhu et al., 2009; Zhao et al., 2013; Hua et al., 2014) and a primary source of water for shallow groundwater recharge, ditches, and streams in this area (Wang and Zhu, 2011; Zhao et al., 2013). This region is a nitrate sensitive area, because the loading of nitrate leaching in the purple soil area is more than 2-fold the average loss in China (Zhou et al., 2013; Zhang et al., 2013). There is severe NO_3^--N pollution of groundwater (mean concentration of NO_3^--N >10 mg L^{-1}) and water eutrophication in the region (Zhu et al., 2009; Wang and Zhu, 2011; Zhou et al., 2013). Moreover, the long-distance movement of N discharged from the purple soil area may have a profound impact on the water quality of the nearby Yangtze River (Wang and Zhu, 2011).

Indirect N_2O emissions from an agricultural drainage ditch mainly receiving interflow were measured for three years *in situ* in southwestern China in this study. The objectives of this study were to quantify the indirect N_2O emissions from agricultural drainage ditches, examine the temporal variation in N_2O emissions, and explore the factors affecting the indirect N_2O emissions, since little is known about the indirect N_2O emissions and EF_{5g} from drainage ditches mainly receiving interflow water in this area.

2. Materials and methods

2.1. Study area

The field study was carried out at the Yanting Agro-Ecological Station of Purple Soil (N 31°16′, E 105°28′), a station of the Chinese Ecosystem Research Network (CERN), Chinese Academy of Sciences (CAS), in an important agricultural area in the upper tributary of the Yangtze River Watershed (Fig. 1a and b). Altitude at the study area ranges between 400 and 600 m, and the surface is mainly covered by low mountains, and hills. The area has a humid subtropical monsoon climate, with an annual (1981–2009) mean temperature of 17.3°C and seasonally variable precipitation of 836 mm spring: 5.9%; summer: 65.5%; autumn: 19.7%; and, winter: 8.9%; from 1981 to 2006 data, after Zhu et al. (2009).

The drainage ditches were located in the valley bottom of a small agricultural catchment (0.15 km^2; Fig. 1b) of the first-order tributary of the Yangtze River (Zhu et al., 2012), where the land use was dominated by sloping farmland of purple soil and forest. The soil is classified as a Regosol (FAO Soil Taxonomy) or a Pup-Orthic-Entisol (Chinese Soil Taxonomy) (Zhu et al., 2012). Land use distribution reflected the topography, with paddy fields on low-lying parts of hills, and farmland on slopes ranging from 3° to 15°. Forestry is mainly concentrated on upper parts of the hills. Rice (*Oryza sativa* L.) is cultivated in the paddies in the rainy season (from the middle of May to September) with applications of 150 kg N ha^{-1}, while oilseed rape (*Brassica napus* L.) is cultivated in the dry season (from late October to early May) with an application of 130 kg N ha^{-1} in late October. Maize (*Zea mays* L.) is planted on sloping farmland in the rainy season and winter wheat (*T. aestivum* L.) is cultivated in the dry season, with applications of 150 kg N ha^{-1} and 130 kg N ha^{-1}, respectively. Forestry is dominated by Alder, *Alnus cremastogyne* Burk., and Cypress (*Cupressus funebris* Endl) plantations. The drainage ditch was surrounded by the upland farmlands, vegetable fields and paddy rice fields (Fig. 1b). The width and depth of the drainage ditch was ~70 cm and 70–100 cm, respectively. The water depth in the ditch, measured using a stainless steel ruler, was shallow (0.6–6.4 cm) with a slow velocity during the observation period, and with sediment depth < 20 cm. The ditch was artificially excavated, and the purplish shale and soil layer interface was exposed to help leaching water laterally flow into the drainage ditch, since the bedrock has extremely weak permeability (Zhu et al., 2009; Zhao et al., 2013, Fig. 1c). Moreover, the local groundwater level is usually very shallow (−45.5–−193.2 cm, Zhang et al., 2017), and the ditch receives shallow groundwater recharge and leaching water for most of the year, while it also receives overland flow for a short period of time (1–2 days) after intensive precipitation. Thus, this drainage ditch receives interflow as the main water source. During the early spring (dry season), there is no water in the drainage ditch for several days. Vegetation in the study ditch mainly comprised *Lolium perenne* L., *Echinochloa crus-galli* (L.) Beauv., *Fimbristylis milliacea* (L.) Vahl, *Polygonum hydropiper*, and other ruderal weeds.

2.2. Sample collection and analysis

The N_2O emissions from drainage ditch were measured *in situ* by