Science of the Total Environment 631–632 (2018) 23–26

Contents lists available at ScienceDirect

Science of the Total Environment

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

Short Communication

Distribution of nitrous oxide emissions from managed organic soils under different land uses estimated by the peat C/N ratio to improve national GHG inventories

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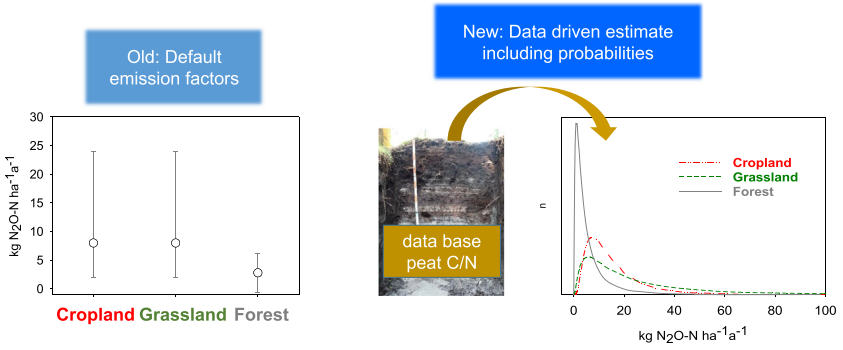
HIGHLIGHTS

- Drained organic soils emit substantial amounts of nitrous oxide (N_2O).
- These emissions are highly positively skewed in Swiss drained organic soils.
- A larger part of N_2O stems from peat decomposition, not fertilization.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 31 July 2017
Received in revised form 27 February 2018
Accepted 27 February 2018
Available online xxxx

Editor: R Ludwig

Keywords:
Histosol
Nitrous oxide
Monte Carlo
Inventory

ABSTRACT

Nitrous oxide (N_2O) contributes substantially to greenhouse gas (GHG) emissions in the agricultural and land-use sectors. Owing to the high effort needed for measuring N_2O emissions and the resulting lack of sufficient field measurements to apply at country-wide scale, soil-borne N_2O emissions are often estimated by applying published IPCC default emission factors. To examine the data reported in the national GHG inventory, the current study utilizes a large data set of soil C/N ratios to predict N_2O emissions and their distribution from drained organic soils in Switzerland. Calculated emission rates increase in the order of forest < grassland < cropland, and they are similar to the mean values currently used in the inventory. Distributions of N_2O emissions are highly positive-skewed and they reveal probabilities of 10 and 14% for cropland and grassland, respectively, to be above 20 kg of N_2O-N per hectare and year. It is likely that the greater part of N_2O from drained organic soil derives from N released upon peat decomposition, and not from fertilization. In conclusion, this research shows that measurement of soil C/N ratios improves the reliability of organic soil N_2O emissions estimates on a national scale and identifies site conditions where future emission measurements would be most effective for reducing the uncertainty in the GHG inventory.

1. Introduction

Histosols are important soil organic matter stores that accumulated ca. 500 Pg of carbon (C) during the Holocene (Loisel et al., 2014; Page et al., 2011; Yu et al., 2010). Together with C, substantial amounts of

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https://doi.org/10.1016/j.scitotenv.2018.02.328
0048-9697/

nitrogen (N) were sequestered (Loisel et al., 2014). Soil C/N ratios in intact peat varies over a wide range, owing to differences in vegetation, site condition, the respective soil layer, and atmospheric N deposition (Limpens et al., 2006). Once drained for agriculture or forestry, organic soils become a substantial source of greenhouse gas (GHG) emissions. Globally, these emissions are estimated at 0.91 - 1.29 Pg CO_2-eq. a^{-1} (Joosten, 2010; Tubiello et al., 2016), of which about 85% originate from CO_2 and 15% from N_2O (Tubiello et al., 2016). Together with drainage-induced peat oxidation, C/N ratios of the remaining organic matter decline, as indicated by a decrease in the C/N ratio from the currently degrading topsoil layers to the underlying, less decomposed peat (Krüger et al., 2015). This pattern is induced by a faster release of C than N when peat degrades, as well as by external N inputs to topsoils from atmospheric deposition and fertilization, and is also accompanied by an increase in soil bulk density.

The important role of drained peatlands as a source of GHG has prompted international activities to compile the respective flux measurements and to generate a comprehensive picture of GHG fluxes from drained organic soils. For the temperate zone, data recently analyzed by (IPCC, 2014) reveal that by gas, CO_2 emissions are the most important, followed by N_2O. Mean N_2O emission factors (EFs) and their 95% uncertainty intervals are 13.0 (8.2–18.0) kg N_2O-N ha^{-1} a^{-1} for drained croplands (CLs) and 2.8 (−0.57–6.1) for drained forests (FLs), respectively. EFs for grasslands (GLs) depend on the status of fertility and drainage, and they range from 0.56 (shallow drained, nutrient-rich) to 11 kg N_2O-N $ha^{-1}a^{-1}$ (deep drained, nutrient-rich).

Because GHG flux measurements require substantial efforts, IPCC default values often serve as standard EFs in many national GHG inventories, but can be improved using country-specific GHG measurements (e.g., (Alm et al., 2007). The IPCC defaults and their uncertainty can be improved, however, also by taking advantage of the relationships between the respective emission rates and soil factors. In histosols, soil C/N ratios are known to be a reliable predictor of N_2O release. In two reviews, (Klemedtsson et al., 2005) and (Mu et al., 2014) showed strongly negative exponential relationships between the C/N ratio of the upper soil (0–0.3 m) and N_2O release. They reported rates of up to 80 kg N_2O-N ha^{-1} a^{-1} for some N-rich topsoils under agricultural management. These rates far exceed the upper 95% confidence interval (CI) for any of the N_2O EFs reported by (IPCC, 2014).

In Switzerland, most organic soils are strongly disturbed and drained (Wüst-Galley and Leifeld, 2017). No N_2O flux measurement of organic soil exists; hence, N_2O EFs of 8 kg N_2O-N ha^{-1} a^{-1} for CLs and GLs (CIs 2–24; (IPCC, 2006) and 2.8 kg N_2O-N ha^{-1} a^{-1} for FLs (CIs −0.6–6.1; (IPCC, 2014) are currently used as the default values in the GHG inventory (FOEN, 2017). The goals of this study were to evaluate whether an emission estimate based on the soil's C/N ratio will change those numbers and to ensure better representation of the associated uncertainty. To do so, organic soils from various sites under different land uses, representing the variability of soil states, were sampled, and the reported relationship between soil C/N and its uncertainty was used to calculate N_2O emissions and their statistical distributions.

2. Material and methods

Peat was sampled from 47 sites in Switzerland using a soil auger. These sites comprise 10 CLs, 11 GLs, and 26 FLs. CLs were on average located at 440 m asl (414–544), GLs at 821 (430–1300), and FLs at 912 (430–1640) m asl. At each site, three separate soil cores were taken, and peat samples of the upper 0–0.3 m were cut into 3–10-cm segments, yielding a total of 572 samples. Soil samples were dried at 105 °C, milled, and measured for C and N content using an elemental analyzer (Hekatech, Germany). Samples from sites containing carbonate were fumigated with HCl overnight in a desiccator before analysis.

Potential N_2O emission rates were calculated based on data published by (Mu et al., 2014) and (Klemedtsson et al., 2005). These authors reviewed the relationship between the C/N ratios of organic topsoils and annual N_2O emissions. Samples from tropical regions in (Mu et al., 2014) were sorted out beforehand, leaving a total of 113 data sets from Scandinavia, the UK, USA, and Canada, considered more representative of Swiss conditions. The ln-ln relationship describing the N_2O emission rates (kg N ha^{-1} a^{-1}) of the resulting data set is:

$$\ln N_2O{-}N = 10.5\ (1.2) {-} 3.19\ (0.7) * \ln C/N \quad (1)$$

where values in parentheses are standard errors of the regression parameters. The model explained 40% of the variability in measured N_2O emissions, slightly more than the data in (Mu et al., 2014) ($R2 = 0.36$), because i) more data from (Klemedtsson et al., 2005) could be included and ii) tropical soils were excluded.

The regression model in Eq. (1) and its parameter uncertainties were used together with C/N ratios, as measured for the 572 soil samples, to estimate N_2O emission rates with Monte Carlo simulation to select randomly 100,000 samples from the distributions. This allowed for the generation of a solid estimate of emissions and for their distributions to be compared with the currently applied standard approach in the inventory. The approach explicitly considers the residual variability that may derive from factors influencing N_2O from these soils other than C/N, e.g. water table depth, peat decomposition rate, and fertilization (Jungkunst et al., 2006), but it cannot quantify the contribution of any of these factors to the unexplained variability.

3. Results

The peat samples were characterized by a wide range of organic carbon (OC) contents and C/N ratios (Table 1). Agricultural peat contained, on average, less OC and had smaller C/N ratios than the FL samples. The maximum OC values were, however, similar across land-use types (always >50%), whereas the maximum C/N ratios were smaller for agricultural than for FL peat (CL < GL < FL). Most relevant—from the perspective of N_2O emission estimates—were the minimum C/N records of between 8.2 and 11.1. The simulated distribution of C/N ratios (Fig. 1) showed that modes were different between agricultural (CL 12.9, GL 12.5) and FL samples (20.4) and that the distribution of the FL C/N ratio was much wider.

A simulation of N_2O emissions returned mean rates of 1.2–7.9 kg N_2O-N ha^{-1} a^{-1} (Table 2). The statistics further revealed that emissions were strongly positively skewed (Fig. 2), thereby mimicking the occurrence of few samples with a wide C/N ratio. Emissions of >20 kg N_2O-N ha^{-1} a^{-1} occur with probabilities of 9.7% (CL), 14% (GL), and <0.5% (FL). At the upper 95th percentile, emissions are 7.5 (FL), 25.5 (CL), and 36.6 (GL) kg N_2O-N ha^{-1} a^{-1}.

4. Discussion

The here suggested revision of N_2O emissions from managed organic soils in Switzerland made use of a large data set of measured soil C/N ratios that represent actual site conditions. It revealed emissions factors that are similar to the default EFs currently applied on a national scale. The new data highlight that for any land-use type, the approach used

Table 1
Overview of the measured C/N ratios and organic carbon contents (OC, %) of topsoil (0–0.3 m) samples from organic soils of three land-use types: cropland CL, grassland GL, and forest FL, in Switzerland. N number of samples, s number of sites.

Land use	CL	GL	FL	CL	GL	FL
	C/N ratio			OC		
N	83	169	320	83	169	320
S	10	11	26	10	11	26
Mean (1 SE)	14.5 (0.3)	16.3 (0.5)	27.3 (0.6)	23.1 (3.4)	29.0 (1.0)	46.2 (0.3)
Median	14.7	13.7	24.3	24.4	25.6	47.5
Min–max	8.2–26.0	9.8–47.0	11.1–95.2	8.7–51.7	11.4–52.6	15.6–55.1