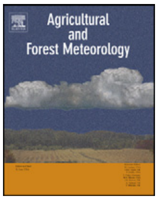
Agricultural and Forest Meteorology 171–172 (2013) 124–136

Contents lists available at SciVerse ScienceDirect

Agricultural and Forest Meteorology

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



Comparison of static chambers to measure CH_4 emissions from soils

Mari K. Pihlatie[a,*], Jesper Riis Christiansen[b,t,1], Hermanni Aaltonen[a,c], Janne F.J. Korhonen[a], Annika Nordbo[a], Terhi Rasilo[d], Giuseppe Benanti[e], Michael Giebels[f], Mohamed Helmy[e], Jatta Sheehy[g,h], Stephanie Jones[i,j], Radoslaw Juszczak[k], Roland Klefoth[l], Raquel Lobo-do-Vale[m], Ana Paula Rosa[n], Peter Schreiber[o,p], Dominique Serça[q], Sara Vicca[r], Benjamin Wolf[s], Jukka Pumpanen[d]

[a] *Department of Physics, Division of Atmospheric Sciences, FI-00014 University of Helsinki, Finland*
[b] *Division of Biomass & Ecosystem Science, University of Copenhagen, Denmark*
[c] *Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland*
[d] *Department of Forest Sciences, FI-00014 University of Helsinki, Finland*
[e] *School of Biology and Environmental Science, University College Dublin, Dublin 4, Ireland*
[f] *Leibniz-Centre for Agricultural Landscape Research, Institute of Landscape Biogeochemistry, Eberswalder Str. 84 D-15374 Müncheberg, Germany*
[g] *MTT Agrifood Research Finland, Plant Production Research, FI-31600 Jokioinen, Finland*
[h] *Department of Plant Sciences, University of California, Davis, CA 95616, USA*
[i] *Scottish Agricultural College, King's Buildings, West Mains Road, Edinburgh EH9 3JG, UK*
[j] *Centre for Ecology and Hydrology (CEH), Edinburgh, Bush Estate, Penicuik, Midlothian EH26 QB, UK*
[k] *Meteorology Department, Poznan University of Life Sciences, Piatkowska 94, 60-649 Poznan, Poland*
[l] *Wageningen UR, Environmental Sciences, Soil Science Centre, P.O. Box 47, 6700 AA Wageningen, The Netherlands*
[m] *Agronomy Institute, Technical University of Lisbon, Tapada da Ajuda 1349-017, Lisboa, Portugal*
[n] *Centre for Environmental Biology, Faculty of Sciences, University of Lisbon, Lisboa, Portugal*
[o] *University of Hamburg, KlimaCampus, Institute of Soil Science, Allende-Platz 2, 20146 Hamburg, Germany*
[p] *Institute of Botany and Landscape Ecology, Ernst Moritz Arndt University Greifswald, Grimmer Str. 88, 17487 Greifswald, Germany*
[q] *Laboratoire d'Aérologie – Observatoire Midi-Pyrénées, FR-31400 Toulouse, France*
[r] *University of Antwerp, Research Group of Plant and Vegetation Ecology, Universiteitsplein 1, 2610 Wilrijk, Belgium*
[s] *Institute for Meteorology and Climate Research (IMK-IFU), Karlsruhe Institute of Technology, Kreuzeckbahnstraße 19, 82467 Garmisch-Partenkirchen, Germany*
[t] *Department of Forest Sciences, Faculty of Forestry, University of British Columbia, Main Mall 2424, V6T1Z4, Vancouver, BC, Canada*

ARTICLE INFO

Article history:
Received 29 September 2011
Received in revised form 30 October 2012
Accepted 12 November 2012

Keywords:
Methane
Soil
Fluxes
Static chamber
Flux calculation

ABSTRACT

The static chamber method (non-flow-through-non-steady-state chambers) is the most common method to measure fluxes of methane (CH_4) from soils. Laboratory comparisons to quantify errors resulting from chamber design, operation and flux calculation methods are rare. We tested fifteen chambers against four flux levels (FL) ranging from 200 to 2300 $\mu g\, CH_4\, m^{-2}\, h^{-1}$. The measurements were conducted on a calibration tank using three quartz sand types with soil porosities of 53% (dry fine sand, S1), 47% (dry coarse sand, S2), and 33% (wetted fine sand, S3). The chambers tested ranged from 0.06 to 1.8 m in height, and 0.02 to 0.195 m^3 in volume, 7 of them were equipped with a fan, and 1 with a vent-tube. We applied linear and exponential flux calculation methods to the chamber data and compared these chamber fluxes to the reference fluxes from the calibration tank.

The chambers underestimated the reference fluxes by on average 33% by the linear flux calculation method (R_{lin}), whereas the chamber fluxes calculated by the exponential flux calculation method (R_{exp}) did not significantly differ from the reference fluxes ($p < 0.05$). The flux under- or overestimations were chamber specific and independent of flux level. Increasing chamber height, area and volume significantly reduced the flux underestimation ($p < 0.05$). Also, the use of non-linear flux calculation method significantly improved the flux estimation; however, simultaneously the uncertainty in the fluxes was increased. We provide correction factors, which can be used to correct the under- or overestimation of the fluxes by the chambers in the experiment.

---

[*] Corresponding author. Tel.: +358 9 19151085; fax: +358 9 19148802.

E-mail addresses: mari.pihlatie@helsinki.fi (M.K. Pihlatie), jrc@life.ku.dk (J.R. Christiansen), hermanni.aaltonen@helsinki.fi (H. Aaltonen), janne.fj.korhonen@helsinki.fi (J.F.J. Korhonen), annika.nordbo@helsinki.fi (A. Nordbo), terhi.rasilo@helsinki.fi (T. Rasilo), giuseppe.benanti@ucdconnect.ie (G. Benanti), michael.giebels@zalf.de (M. Giebels), helmyhammad@gmail.com (M. Helmy), jatta.sheehy@mtt.fi (J. Sheehy), Stephanie.Jones@sruc.ac.uk (S. Jones), radjusz@up.poznan.pl (R. Juszczak), roland.klefoth@wur.nl (R. Klefoth), raquelvale@isa.utl.pt (R. Lobo-do-Vale), paulayana@gmail.com (A.P. Rosa), peter.schreiber@zmaw.de (P. Schreiber), dominique.serca@aero.obs-mip.fr (D. Serça), sara.vicca@ua.ac.be (S. Vicca), benjamin.wolf@kit.edu (B. Wolf), jukka.pumpanen@helsinki.fi (J. Pumpanen).

[1] Present address: Department of Forest Sciences, University of British Columbia, Vancouver, Canada.

0168-1923/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agrformet.2012.11.008

1. Introduction

The static chamber method (non-flow-through-non-steady-state chamber, Livingston and Hutchinson, 1995) is the most commonly used method to measure non-reactive greenhouse gas (GHG) fluxes, especially methane (CH_4) and nitrous oxide (N_2O), from soils. The basic principle of this technique is to cover a known area of soil with a closed chamber that allows the gas exchange between the soil below the chamber and the chamber headspace. The gas concentration change over time inside the chamber headspace is quantified and translated into a flux rate, representing the flux into or out of the soil.

Debates on how to design an optimal chamber and how to calculate the gas fluxes from soils have been going on for more than 30 years (e.g. Anthony et al., 1995; Conen and Smith, 2000; Forbrich et al., 2010; Hutchinson and Mosier, 1981; Kroon et al., 2008; Kutzbach et al., 2007; Livingston et al., 2005, 2006; Matthias et al., 1978; Pedersen et al., 2010). Recommendations of using a fan to mix the chamber headspace (Christiansen et al., 2011; Pumpanen et al., 2004), a vent tube to minimize pressure changes in the chamber (Hutchinson and Livingston, 2001; Hutchinson and Mosier, 1981; Xu et al., 2006), and a proper insulation or construction to avoid uncontrolled leakage from the chamber (Hutchinson and Livingston, 2001) are still being discussed and are not widely adopted. The effect of chamber size and geometry on GHG fluxes has not been as widely discussed or tested, although they are key issues in assessing how well the chamber is able to detect the GHG fluxes. In addition, linear regression is the most common method to calculate chamber based CH_4 and N_2O fluxes from soils, though it has been documented to lead to systematic underestimation of the fluxes (Anthony et al., 1995; Gao and Yates, 1998a; Livingston et al., 2005; Kroon et al., 2008; Kutzbach et al., 2007; Pedersen et al., 2010).

Emission measurements of greenhouse gases with closed static chambers imply that the concentration of the target gas increases in the headspace. This gas accumulation decreases the natural concentration gradient between the soil and the chamber headspace and may significantly reduce the gas efflux (Davidson et al., 2002; Kutzbach et al., 2007; Livingston and Hutchinson, 1995; Nay et al., 1994). The purpose of the flux measurement is to obtain an estimate of the undisturbed flux, the flux prior to the chamber deployment. When applying linear regression, one assumes that the gas concentration gradient between the source and the atmosphere does not change, and that the flux is constant during the entire enclosure. A non-linear function (e.g. exponential function) implicitly accounts for the decreasing efflux during the enclosure and estimates the flux at time zero of the chamber closure.

Inter-comparisons of different chamber designs in controlled conditions in combination with different flux calculation methods are scarce and the focus has been on CO_2 (Butnor and Johnsen, 2004; Gao and Yates, 1998b; Nay et al., 1994; Widen and Lindroth, 2003). Pumpanen et al. (2004) performed a chamber calibration campaign for 20 different CO_2 efflux chambers representing static chambers (non-flow-through-non-steady-state chamber), closed dynamic chambers (flowed-through-non-steady-state) and open dynamic chambers (flow-through-steady-state). They found that the bias of the CO_2 fluxes was greatest with static chambers, which underestimated or overestimated the fluxes between −35 and +6% depending on the type of chamber, gas sampling and analysis, and the method of mixing the chamber headspace air. The largest underestimations were observed with static chambers based on syringe gas sampling, which is the most common method in the flux measurements of CH_4 and N_2O fluxes.

Even though the studies with CO_2 chambers have identified critical issues regarding chamber design and sampling, the results are not directly applicable to chambers used for non-CO_2 greenhouse gases, such as CH_4 and N_2O. First of all, chamber designs and sampling protocols are often different. CH_4 and N_2O are most often sampled manually in the field and subsequently analyzed off-site using gas chromatographic methods. In contrast, CO_2 fluxes are typically determined *in situ* using online analyzers connected to dynamic chambers with a constant headspace mixing. Furthermore, CO_2 fluxes can be several degrees of magnitude larger than CH_4 and N_2O fluxes, leading to higher concentration change within chamber headspace over an enclosure, and allowing for a lower sensitivity of the gas analyzers and shorter enclosure times.

In order to minimize the errors related to the measurements of non-CO_2 greenhouse gas exchange, such as CH_4 and N_2O, there is an urgent need to perform similar evaluation of the chambers in controlled laboratory conditions. We organized a static chamber comparison campaign to gain new knowledge on the differences between static chambers typically used to measure CH_4 and N_2O fluxes from soils. Both CH_4 and N_2O were measured in the experiment; however, here we report the results of CH_4 only. The tested chambers differed in size, shape and material, and were originally operated in different ecosystems (peatlands, forests, agricultural fields). Christiansen et al. (2011) report the effects of chamber placement, manual sampling and headspace mixing on CH_4 fluxes for two static chambers. Here we report the results of a comparison of 15 chambers, and provide general guidelines for chamber designs and flux calculation procedures.

The overall aims of the campaign were (1) to quantitatively assess the uncertainties and errors related to static chamber measurements, (2) explain uncertainties and errors by chamber design and flux calculation methods, and (3) to provide guidelines for static chamber designs, sampling procedures, and flux calculation methods.

2. Materials and methods

2.1. Calibration system

The calibration campaign took place at Hyytiälä Forestry Field Station (61°51′N, 24°17′E), 152 m above sea level between 11th of August and 10th of October 2008. The calibration system was originally built for CO_2 chamber calibration and is presented in detail by Pumpanen et al. (2004). A schematic presentation of the measurement setup is presented in Fig. 1.

The principle of the calibration system is to establish a controlled diffusive gas flux through a porous medium (sand bed) of a known density and porosity. The flux is created by injecting a known concentration of the target gas into a tank with defined volume and a homogenous sand bed on the top. The concentration gradient between air inside and outside the tank drives the diffusive flux from the tank through the sand bed. This flux is referred to as the reference flux in this paper. The calibration system can strictly be viewed as a non-steady-state system because the concentration in the tank decreases over time. This decrease in the concentration, however, is so small that the reference flux can be assumed as constant (see Section 4.1).

Simultaneous chamber measurements on the top of the sand bed enable direct comparison between the chamber and the reference fluxes, and allows for a subsequent quantification of the potential under- or overestimations of each tested chamber.

The calibration system consisted of a cylindrical stainless steel tank (diameter 1.13 m, height 1.0 m) with a 0.15 m thick sand bed (diameter 1.0 m) on the top. The sand was placed on top of a 0.02 m thick perforated high-density polyethylene lid, which allowed air to move freely between the sand and the tank. A porous polypropylene gauze was placed between the sand and the lid to prevent the sand from falling into the tank. Air inside the tank was