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Towards a standard non-steady-state chamber methodology for measuring soil N_2O emissions

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ABSTRACT

Nitrogen transformations in agricultural soils are a major source of N_2O, a potent greenhouse gas that also contributes to stratospheric ozone destruction. Nearly all reports of *in situ* soil N_2O emission (F_{N_2O}) were obtained using non-flow-through non-steady-state (NSS) chambers. Deficiencies in design and deployment of NSS chambers have led to unreliable data and large uncertainty in measurement of soil N_2O fluxes. In this opinion paper, I propose that the scientific community agree on a standard NSS chamber methodology with a set of minimum requirements. Wide adoption of a standard methodology would improve the reliability and creditability of reported measurements, ensure methodological consistency, and allow comparisons among studies. It would also guide editors and reviewers in assessing the quality of manuscripts based on NSS chamber measurements.

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1. Introduction

Nitrous oxide is the third most anthropogenically emitted greenhouse gas (GHG) when expressed as CO_2-eqv. In many developed countries, ~2/3 of national human induced N_2O emissions are attributed to nitrification and denitrification of N added to agricultural soils in synthetic fertilizers, manure and organic residues (USEPA, 2010). Even on livestock farms, where enteric fermentation and manure management are large emission sources, soil N_2O can still contribute up to 50% of total farm GHG.

Accurate measurements of soil N_2O emissions are needed to improve understanding of N dynamics and controlling factors, and to support national GHG inventories and assessment of mitigations. While soil N_2O fluxes can be measured using several methods, more than 95% of field data reported in the literature were obtained using non-flow-through non-steady-state (NSS) chambers (Rochette and Bertrand, 2008). Consequently, most of what we know about soil N_2O dynamics has come from NSS chambers. More specifically, the accuracy of emission estimates, assessment of mitigations, calibration of predictive models, calculation of empirical emission factors (such as those of Inter-governmental Panel on Climate Change (2006)) and estimation of national emission inventories all depend on the quality of NSS chamber measurements.

Abbreviations: GHG, greenhouse gas; NSS, Non-flow-through non-steady-state (chamber); T_s, soil temperature; T_a, air temperature; ΔT, temperature difference; $[N_2O]$, nitrous oxide concentration; F_{N_2O}, Soil N_2O emission.

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Rochette and Eriksen-Hamel (2008) reviewed studies reporting NSS chamber measurements of soil N_2O emissions and concluded, based on evaluation against specific criteria that more than half of the N_2O data were of poor to very poor quality. This finding, along with recent development of less intrusive micrometeorological approaches questions the need to continue to use chamber techniques to measure soil N_2O emissions. I argue that NSS chambers still have an important role in soil N_2O research, due to several advantages, but that NSS chambers will improve our understanding of soil N_2O emissions if the methods are sufficiently sound to yield reliable results.

My objective is to propose establishment of an international standard for NSS chamber methodology. A major strength of NSS chambers is that their design and deployment protocol can be adapted to a wide range of situations. Rather than prescribe a fixed, universally applicable methodology, I propose a set of minimum requirements needed to obtain reliable N_2O flux measurements. Such information would help researchers obtain data that could more easily be compared to results from other studies, and would also serve as guidelines in reviewing reported values in manuscripts.

2. Major issues with NSS chamber methodology

Placing chambers on a soil surface often modifies the gas flux to be measured by changing the vertical profile of the gas concentration, the energy balance, and the turbulence regime. Chambers are therefore an invasive method and precautions need to be taken to minimize biases in flux estimates (Livingston and Hutchinson, 1995; Hutchinson and Livingston, 2002; Rochette and Hutchinson, 2005; Rochette and Bertrand, 2008). The most important concerns can be grouped into three categories, based on effects on N_2O production and transport in soils, soil-chamber gas transfer, and leakage from and contamination of chamber headspace and air samples.

2.1. N_2O production and transport in soil

Nitrous oxide is produced in soils by transformations of mineral N. Emission of N_2O at the soil surface is not necessarily a measure of real time net soil N_2O production because N_2O transport away from its production site varies in time in response to the changing soil environment. Consequently, changes in soil properties during NSS chamber deployment may bias flux estimates by altering gas production and transport processes. Chamber placement can affect the rate of these processes by influencing soil temperature, soil water content, soil disturbance, barometric pressure fluctuations and root activity.

2.1.1. Soil temperature

Gas production and consumption vary with depth in soils, but most occurs at shallow depths and so changes in surface soil temperature (T_s) should be minimized when NSS chambers are deployed. Chambers can increase or decrease T_s depending on chamber wall properties, solar radiation, soil surface wetness, and other factors. For example, small differences in soil–surface T_s (ΔT_s) can occur beneath clear chambers compared with non-covered controls (Coleman, 1973; Matthias et al., 1980; Sharkov, 1984), while temperature at 1 cm depth decreased by as much as 9 °C during 30 min deployment of an opaque chamber (Reichman and Rolston, 2002). For longer deployment periods, much larger ΔT_s were measured, varying from +5 °C for plexiglass to −18 °C for insulated reflective steel chambers.

Chamber wall properties that best minimize ΔT_s depend on environmental conditions (*i.e.*, clear *versus* cloudy sky; wet *versus* dry soil; Matthias and Peralta-Hernández, 1998). Large changes in soil temperature are expected when chambers are placed on a dry soil exposed to solar radiation, but impacts should be small on a wet soil in shaded environments. While some ΔT cannot be avoided, it can be minimized (<2 °C) using insulated chambers with reflective covers and short deployments (Matthias et al., 1980).

2.1.2. Soil water content

Soil water content strongly affects F_{N_2O} by its influence on microbial activity and on gas transport rate (Skiba and Smith, 2000; Smith et al., 2003). Rates of gas diffusion are four orders of magnitude slower in water than in air and, consequently, soil water content affects diffusion of O_2, and hence redox potential, and also the residence time of N_2O in soil, thereby affecting the probability for microbial reduction to N_2 before it reaches the soil surface. Chambers or collars can modify soil moisture by intercepting or excluding rainfall and run off water, and by reducing evaporation (Edwards, 1974; Yao et al., 2009), but these effects are usually negligible in N_2O studies because chambers are in place for only a short time. Low profile collars nearly flush with the soil surface can minimize micro-climate issues (Venterea et al., 2010). However, the presence of a collar may, over time, affect the hydrological regime by interfering with surface lateral water flow. Collars should be relocated if the enclosed soil water content differs from that in adjacent soil.

2.1.3. Root activity

In most ecosystems, roots are near the soil surface and inserting chambers or frames to 10 cm results in considerable root damage. Changes in root activity as a result of chamber insertion can affect the flux in several ways. Roots have a direct effect when they emit the target gas (*e.g.*, CO_2) but they also have an indirect effect when they alter soil conditions and influence gas dynamics by changing water and nutrient uptake, and by releasing organic exudates. Ideally, the delay between collar

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