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Physical and hydric factors regulating nitrous oxide and methane fluxes in mountainous Atlantic forest soils in southeastern Brazil

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Abstract

Nitrous oxide (N_2O) and methane (CH_4) are gases that act in physical and chemical processes related to global climate control and ozone layer stability. Atlantic forest soils are natural emitters of N_2O and act in the consumption of CH_4 when well aerated. Understanding the dynamics of N_2O and CH_4 fluxes is of great importance because the exchange of gases between the soil and the atmosphere is susceptible to climate change. The objective of this work was to evaluate N_2O and CH_4 fluxes using static chambers against different physical and hydric factors (e.g., soil temperature, precipitation, water filled pore space (WFPS), soil texture) in soils of different altitudes and rainfall. The mean annual N_2O fluxes obtained at the study sites were: 0.87, 0.25 and 0.58 kg N ha^{-1} year^{-1} for altitudes 430, 1150 and 1120 m, respectively. These values are lower than averages reported for tropical forests in the world, including the Amazon rainforest, but they are higher than those reported for cerrado. The soils proved to be sinks of atmospheric CH_4 with annual consumption of 3.2 and 2.0 kg C ha^{-1} year^{-1} for 430 and 1150 m, respectively. These values are very close to the reported ranges of CH_4 uptake by soils of tropical forests in the world, but they are lower than the reported averages for cerrado. Monthly precipitation, WFPS, temperature, and soil texture were the main regulators of N_2O fluxes in soils at the study sites. At lower altitude, the consumption of atmospheric CH_4 by the soil surface reduces with increasing precipitation. WFPS between 45 and 50% appears to be more favorable for CH_4 consumption by the soil surface.

Introduction

Nitrous oxide (N_2O) and methane (CH_4) concentrations have been increasing significantly in the atmosphere since the pre-industrial period, driven mainly by the intensification of socioeconomic development's anthropogenic activities, especially agricultural activities (TIAN et al., 2018; THOMPSON et al., 2019). The global average concentrations of N_2O and CH_4 in 2021 were respectively 333 and 1880 ppb (NOAA, 2022a, 2022b), which represent increases of 22 and 170% relative to pre-industrial levels (IPCC et al., 2014). Tropospheric N_2O and CH_4 account for the greatest global warming potentials among the main greenhouse gases (GHGs), with values 265 and 28 times higher than carbon dioxide (CO_2), respectively (IPCC et al., 2014). Additionally, the CH_4 acts in the production of tropospheric ozone (O_3), a harmful pollutant to human health and ecosystems (FIORE et al., D08307). N_2O is, currently, the main substance emitted by anthropogenic activities, acting indirectly in the depletion of stratospheric O_3 (RAVISHANKARA et al., 2009; MÜLLER, 2021).

Among the different sources of N_2O, Syakila and Kroeze (2011) suggest that natural soils may act as the main source of N_2O in the atmosphere, representing 56–70% of the estimated N_2O global flux. Soils with tropical forests cover have an estimated global contribution of 1.3 Tg N year^{-1} (WERNER et al., 2007). The fluxes of N_2O at the soil-atmosphere interface can occur (1) under aerobic conditions, where N_2O is produced as a by-product of the mechanism of ammonium oxidation (NH_4^+) to nitrite (NO_2^-) in the nitrification process, and (2) under suboxic conditions N_2O is an intermediate product in the denitrification process, which comprises the mechanism of nitrate reduction (NO_3^-) to molecular nitrogen (N_2) (WRAGE et al., 2001).

For CH_4, tropical forest soils generally are considered as a potential sink (~4.6 Tg C year^{-1}) and contribute about 28% of the global consumption in soils of CH_4 (DUTAUR and VERCHOT, 2007). The fluxes of CH_4 at the soil-atmosphere interface is a net result between methanogenesis (microbial production) and methanotrophy (microbial consumption). Methanogenesis can occur in forest soils in aggregates where there are anaerobe microsites (DUTAUR and VERCHOT, 2007). On the other hand, methanotrophy is the dominant process in tropical forest soils, where oxidation generally exceeds production, and therefore CH_4 transfer from the atmosphere to the soils is observed (DUTAUR and VERCHOT, 2007; SABREKOV et al., 2016).

Different factors potentially regulate the production (and consumption) processes of N_2O and CH_4 in soils, such as (i) soil temperature, where the increase in temperature leads to the intensification of microbial activity and greater availability of nutrients, (ii) soil texture that works by controlling permeability and resistance to gas transport and (iii) precipitation and water-filled pore space (WFPS). WFPS may become a factor responsible for the variability of CH_4 and N_2O fluxes because it regulates the redox conditions of the environment, favoring the occurrence of a certain microbiological process (DAVIDSON, 1991; MOREIRA and SIQUEIRA, 2006). Among the several studies on N_2O and CH_4 fluxes in Brazilian tropical rainforest soils, only a few were conducted in the Atlantic Forest (DE SANTOS, 1997; MADDOCK; DOS SANTOS; PRATA, 2001; COSTA, 2002; PERRY, 2011; SOUSA NETO et al., 2011; RODRIGUES and DE MELLO, 2012), however only one of them (SOUSA NETO et al., 2011) addressed fluxes of these two GHGs simultaneously with soil temperature, precipitation and WFPS as flux control factors.

This work aims to assess the effect of some physical and hydric factors (e.g., soil temperature, soil texture, rainfall, WFPS) on the regulation of N_2O and CH_4 fluxes across the soil-atmosphere interface of different mountainous areas with Atlantic Forest cover in Southeastern Brazil. The exchange of gases between soil and atmosphere is potentially susceptible to climate change, and thus, understanding the dynamics of N_2O and CH_4 fluxes in the Atlantic Forest soils is of great importance.

Section snippets

Study area

The study was carried out in mountainous areas with Atlantic Forest coverage, located within the limits of two federal conservation units: (i) *Serra dos Órgãos* National Park (PARNASO) and (ii) *Caparaó* National Park (PARNA Caparaó) (Fig. 1).

PARNASO covers approximately 11 thousand hectares comprising four municipalities (*Petrópolis, Magé, Guapimirim, and Teresópolis*) in Rio de Janeiro state (RJ). The vegetation cover is characterized as Ombrophilous Dense Forest and classified according to…

Physical soil properties

During the sampling campaigns, the temperature on the soil surface (1–2 cm) in SOSB430 ranged from 18.1 °C (August 2019) to 23.2 °C (February 2020), while in SOBM1150, it ranged from 12.6 °C (July 2019) to 19.9 °C (December 2019). In SCSM1120, it ranged from 16.5 °C

(August 2019) to 22.0 °C (February 2019). In the SCSM1120 sampling campaigns in January 2020, due to heavy rains (5 days duration), the average soil temperature was 19.0 °C (Fig. 2). The results show a range between winter and…

N_2O and CH_4 annual fluxes

In SOSB430, the average annual N_2O flux (0.87 kg N ha^{-1} year^{-1}) found in this study was close to the upper limit of the range of average fluxes reported on studies carried out in Atlantic Forest coverage areas (0.64–0.90 kg N ha^{-1} year^{-1}), whose altitudes were similar (DE MELLO; GOREAU, 1998; PERRY, 2011; SOUSA NETO et al., 2011). SOSB430's N_2O annual emission represents 5–6% of the atmospheric input of N reported by de Souza et al. (2015) and Ponette-González et al. (2017), measured in this…

Conclusion

Annual means of N_2O flux in the submontane forest of *Serra dos Órgãos* was 0.87 kg N ha^{-1} year^{-1}, which represents 5–6% of the atmospheric N input via bulk deposition. The annual means of N_2O fluxes in the montane forest of *Serra dos Órgãos* and *Serra do Caparaó* were 0.25 and 0.58 kg N ha^{-1} year^{-1}, respectively. The values found were within the range reported by other studies for soils with Atlantic Forest cover (≤1 kg N ha^{-1} year^{-1}), however they are lower than the emissions reported in the…

CRediT authorship contribution statement

Letícia M. Mombrini: Writing – original draft, Methodology, Formal analysis. **William Z. de Mello:** Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing. **Renato P. Ribeiro:** Methodology, Formal analysis. **Caio R.M. Silva:** Formal analysis, Methodology. **Carla S. Silveira:** Supervision, Resources, Funding acquisition, Writing – review & editing.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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