Impacts of land use and land cover changes on nitrous oxide emissions in the Brazilian semiarid

Kelly Ribeiro[1], Eráclito Rodrigues de Sousa-Neto[1], Paulo José Duarte-Neto[2], Jean Pierre Henry Baulbaud Ometto[1], Rômulo Menezes[3], Willian José Ferreira[1].

[1]Centro de Ciências do Sistema Terrestre – CCST, Instituto Nacional de Pesquisas Espaciais – INPE, São José dos Campos, SP, Brazil
[2]Departamento de Estatística e Informática, Universidade Federal Rural de Pernambuco - UFRPE, Recife, PE, Brazil
[3]Universidade Federal de Pernambuco - UFPE, Recife, PE, Brazil

Abstract
Arid and semiarid lands cover about 30% of the earth surface and may be increasing due to global change. Furthermore, semiarid zones are poorly understood and their contribution to the budges of atmospheric gases such as nitrogen oxides are extremely sparse. In Brazil, semiarid lands totalize 980,133 km_2, which has a population of ~22.6 million inhabitants. This semiarid region undergoes natural lengthy periods of drought that cause losses in crop and livestock productivity, having severe impact on the population. Due to the regions vulnerability to climate change, livestock has emerged as the main livelihood of the rural population, being the precursor of the replacement of native vegetation by grazing areas. This study aimed to measure nitrous oxide emissions (N_2O) from two different soil covers: a native forest and a pasture in the municipality of São João, Pernambuco State, in the years 2013 and 2014. N_2O measurements were made by using static chamber techniques. Nitrous oxide emissions ranged from -1.0 to 4.2 mg m^{-2} d^{-1} and -1.22 to 3.4 mg m^{-2} d^{-1} in the pasture and native forest, respectively, and they did not significantly differ from each other. Emissions were significantly higher during dry seasons and correlated with high temperatures. In this study, soil gas fluxes seemed to be more influenced by climatic and edaphic conditions than by soil cover in the semiarid regions.

Key Words
Native vegetation, pasture, greenhouse gases (GHG), climatic conditions.

Introduction
The Caatinga is a biome located in a semiarid region with unique characteristics that make it an exclusive Brazilian biome (Gariglio et al., 2010). The Caatinga represents 11% of the Brazilian territory, which means an area of about 844,453 km² of the interior of the Northeast region (Gariglio et al., 2010). An important feature of the region is the severe drought periods that affect plant growth and have substantial social and economic impact on the population. Since agriculture is vulnerable to climate change, livestock has emerged as the main activity of the rural population, being the precursor of systematic replacement of native vegetation by grazing areas and responsible for serious environmental problems such as loss of biodiversity and desertification (de Freitas et al., 2007; Leal et al., 2005; MMA, 1998). Livestock is considered one of the major sources of greenhouse gas emissions (GHG) to the atmosphere, mainly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which results from enteric fermentation, manure management, feed production, as well as indirectly from change in land use (USDA, 2008). Thus, this study aimed to measure N_2O soil emissions from a natural forest (Caatinga) and a pasture (for livestock) in order to assess the impact of changes in land use and soil gas emissions to atmosphere on a local and regional scale, and to evaluate the impact of these processes on this vast and poorly known semiarid ecosystem.

Methods

Study site

This study was conducted on a farm named Riacho do Papagaio, in São João municipality (8°48'35" S, 36°24'20" W, 690 meters a.s.l.) in the State of Pernambuco, Brazil. At Riacho do Papagaio farm, the pasture was established in 1950 (personal communication by the farm owner) when the native Caatinga forest was cut down and replaced by Guatemala grass (*Tripsacumlaxum* Nash), a perennial forage.

Experiment design and collection of soil gas fluxes

This experiment was set up in two different soil covers: a Caatinga forest and a pasture (grazing). Both covers are located in the same farm. The fieldwork occurred in 2013 and 2014, with two campaigns per year: one in the dry season (September – April) and the other in the rainy season (May to August).

In each treatment, we measured fluxes of nitrous oxide (N_2O) along three 20 m lines that were established at randomized seed points and followed randomized directions. Each line held six cylindrical PVC chambers (replicates) consisting of a pipe that served as a base (0.24 m diameter) and a cap that fit snugly on the base. Gas collection of each line occurred in different periods of the day (L1: 08H00 – 09H00, L2: 12H00 – 13H00 and L3: 16H00 – 17H00) in order to capture fluxes in different temperature conditions.

Four samples of 60 mL of the air from the chambers were withdrawn at intervals of 1, 10, 20 and 30 min after closing with 60 mL syringes and then transferred to previously evacuated glass serum vials sealed with gas impermeable, butyl rubber septum stoppers (Sousa-Neto, 2012). The samples were analysed at the by gas chromatography (SHIMADZU GC-14A Model) and the N2O fluxes were determined from the temporal variation of its mixing ratios inside the chamber during the sampling time (Matthias et al., 1980). The limit of detection (LOD) of tehe developed analytical method was determined in successive chromatograms of two mixtures with decreasing concentrations (1100 ppb and 315 ppb). The lowest concentration that generate analytical signal was considered as LOD (30 ppb) and the limit of quantification (LOQ) was calculated based on the 10:1 ratio, i.e. 10LOQ: 1LOD (Ripp, 1996).

Statistical analysis

All variables were tested for normal distribution and homogeneity of variance prior to any statistical analysis using Kolmogorov-Smirnov and Levene's tests, respectively. Data were transformed using box-cox transformation whether the data did not fit the normal distribution curve. We analysed gas flux averages and soil temperature and moisture in a 2-way ANOVA design comparing the response variables among treatments, season, and year. Tukey's post-hoc analysis was used to clarify any significant difference detected by ANOVA. Linear Pearson correlation analysis and linear regression analysis were used to verify a possible relationship between mean gas fluxes and soil temperature and moisture. All tests were assumed significant at $P < 0.05$. Statistical analyses were performed using Statistica v. 12.0 (Statsoft, Tulsa, OK, EUA).

Results

Edaphic and climatic conditions

Higher soil temperature were found during dry seasons for both years in both Caatinga and Pasture treatments ($P = 0.000$; Figure 1). Mean soil temperatures measured during the dry season in 2013 and 2014 were 31.9±3.0 °C and 29.4±3.0 °C, respectively. During the rainy season, mean soil temperatures were 24.7±1.4 °C and 22.8±1.7 °C for 2013 and 2014, respectively. Temperatures were also different between treatments ($P = 0.005$): pasture soil temperature (mean 27.0±4.2 °C) was two degrees warmer than Caatinga soil temperature (mean 25.8±40 °C). Throughout the day, higher temperatures were measured between 12H00 and 16H00 ($P = 0.000$), and values ranged between 20.7 °C and 37.3 °C. During the morning (~09H00), temperatures were approximately three degrees lower than in the afternoon (Figure 1).

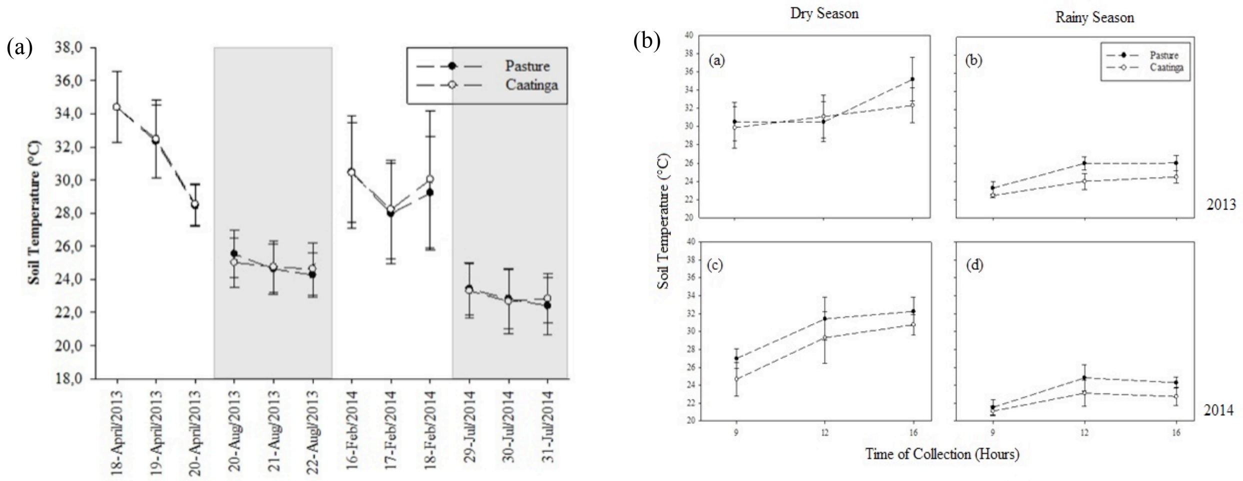

Figure 1. (a) Soil temperature measured during rainy (shaded regions) and dry season of 2013 and 2014. Solid symbols represent pasture and open symbols represent Caatinga forest. (b) Daily soil temperature measured every collection day of each campaign in 2013 and 2014: dry season (a and c) and rainy season (b and d) in the pasture (closed symbols) and Caatinga (open symbols)

Nitrous oxide emissions- N_2O

Nitrous oxide fluxes ranged from -1.0 to 4.2 mg m^{-2} d^{-1} and -1.22 to 3.4 mg m^{-2} d^{-1}, in the pasture (annual average: 0.30±0.03 mg m^{-2} d^{-1}) and in the Caatinga (annual average: 0.23±0.02 mg m^{-2} d^{-1}), respectively (Figure 2). No significant differences were found between data from Caatinga and Pasture. Comparing fluxes between the two years of sampling, N_2O was significantly higher in 2014 than in 2013 ($P = 0.0000$) in both treatments. Seasonally, N_2O emissions were higher in the dry season compared to the rainy season, for both 2013 and 2014 ($P = 0.0000$).

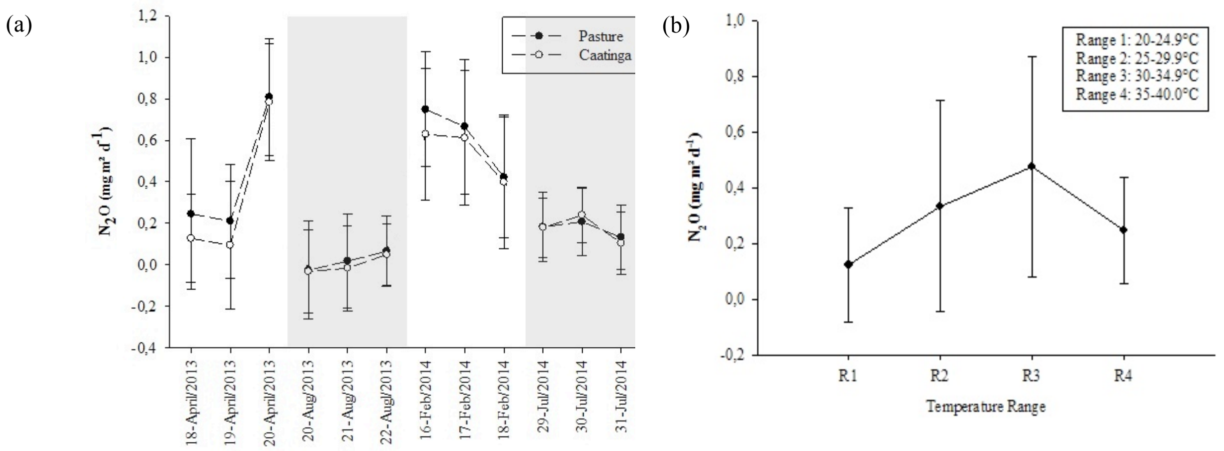

Figure 2. (a) Soil nitrous oxide fluxes (mg m^{-2} d^{-1}) measured in the pasture and in the Caatinga forest in Pernambuco State in rainy (shaded regions) and dry seasons of 2013 and 2014. Solid symbols correspond to pasture and open symbols correspond to Caatinga; (b) Nitrous oxide emissions according to different soil temperature ranges: R1 (20 - 24.9°C), R2 (25 - 29.9°C), R3 (30 – 34.9°C), and R4 (35 – 40°C).

Nitrous oxide fluxes seemed to be influenced by different temperature ranges ($r = 0.36$; $P = 0.000$; Figure 2b). In a range of temperatures from 30 °C to 34.9 °C (R3), emissions were significantly higher in the other temperature ranges ($P = 0.000$). Fluxes did not present significant correlation with soil moisture (not presented here).

In this study, soil cover did not significantly influence soil gas fluxes. Instead, soil fluxes were influenced by climatic and edaphic conditions. Our results show that N_2O fluxes were mostly positive, indicating emission of GHG from soil to atmosphere and that emissions vary with season. It is known that soil N_2O emissions can be highly variable over time and they are regulated by different factors such as soil water content, temperature, aeration, ammonium, and nitrate concentrations, pH, mineralizable C, among others

(Bouwman, 1990; Ponce-Mendoza et al., 2010). Nevertheless, N_2O emissions were related only to temperature and high N_2O soil emissions were found in samples collected in the dry season, and they were significantly associated with soil temperature in the range of 30 – 35 °C, which shows the influence of temperature over the nitrogen dynamics. Such influence of temperature over N_2O emissions has been shown in other studies (Garcia-Montiel et al. 2003; Sousa-Neto, 2012). Scenarios for the Brazilian Northeast region indicate a rise in temperature between 0.5 and 4°C by 2100 and a reduction of precipitation of 10-20% (IPCC, 2014; Marengo et al., 2009), which raises concerns for future N_2O emissions.
No differences of N_2O emissions were found between Caatinga and pasture in the region of study, and monthly mean flux values seem to be almost overlapping as shown in Figure 2. Such proximity of mean fluxes may suggest that soil of both treatments (regardless of coverage) might be similar in terms of N content, which could explain the similarity in N_2O fluxes. Furthermore, according to some studies, semiarid soils are considered poor regarding stocks of N (Menezes et al., 2012)

Conclusion

Our findings show that in the region of study, the changes in land cover are not the major drivers of significant emissions, and they showed the influence of edaphic conditions and climatic factors over soil gas production. In addition, they show that, together, soil cover type and climatic condition may positively affect the GHG production leading to significant emission to the atmosphere. Moreover, land use changes impact important soil attributes such as humidity, temperature and structure, exposing the surface to direct solar radiation, thus altering microbiological dynamics, varying between high and low soil respiration rates and thus resulting in higher/low emissions of GHG. The organic matter, availability of nutrients, and microbial activity are minimized in very dry soil conditions and the occurrence of rainfall events stimulates microbiological activities increasing emissions of N_2O. The environmental variables (temperature and soil moisture) are important regulators in GHG; however, the climate and high rainfall variability inherent in the environment, associated with anthropogenic changes in the region hamper determining emissions trends for the biome. Unfortunately, our data covers only few days of each season and extrapolations cannot represent the processes of the entire biome. Thus, our study remarks that the knowledge of the dynamics of greenhouse gases in semiarid regions is of great importance for understanding of global climate change, as arid and semiarid lands cover approximately 41% of the Earth's surface. Thus, studies that include the understanding of the dynamics of biogeochemical cycles should be expanded to many other areas of the Brazilian semiarid

Acknowledgement

We thank FAPESP/FACEPE for the financial support given under the project 2009/52468-0; InterAmerican Institute for Global Change Research (IAI) under the project Nnet CRN3005. We are also grateful to the Riacho do Papagaio farm for letting us install our experiment on their property, and to the Federal Rural University of Pernambuco for laboratory support and fieldwork by students. We thank the laboratory of Gas Chromatography of INPE for the analysis of our samples. We are grateful to the support given by the board of research and technicians MS. Willian José Ferreira, Dr. Maria Cristina Forti, MS. Karinne Reis Deusdará Leal, Eng. Jorge Jofre and Mariana de Almeida Souza.

References

Bouwman A. Soils and the greenhouse effect: The Present Status and Future Trends Concerning the Effect of Soils and Their Cover on the Fluxes of Greenhouse Gas John Wiley & Sons Inc, 1990.

de Freitas RAC, Sizenando Filho FA, Maracajá PB, Diniz Filho ET, de Lira JFB. Estudo florístico e fitosociológico do extrato arbustivo-arboreo de dois ambientes em Messias Targino divisa RN/PB. Revista Verde de Agroecologia e Desenvolvimento Sustentável 2007; 2.

Garcia-Montiel DC, Steudler PA, Piccolo M, Neill C, Melillo J, Cerri CC. Nitrogen oxide emissions following wetting of dry soils in forest and pastures in Rondônia, Brazil. Biogeochemistry; 64: 319-336, 2003.

Gariglio MA, Sampaio EVdSB, Cestaro LA, Kageyama PY. Uso sustentável e conservação dos recursos florestais da caatinga: Serviço Florestal Brasileiro-SFB, 2010.

IPCC. Intergovernmental Panel on Climate Change - Climate Change 2014: Inpact, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifthe Assessment Report of the Intergovernmental Panel on Climate Change. In: Field Cea, editor. Cambridge University Press, Cambridge/New York, 2014.

Leal IR, Silva Jd, Tabarelli M, Lacher Jr TE. Mudando o curso da conservação da biodiversidade na

Caatinga do Nordeste do Brasil. Megadiversidade 2005; 1: 139-146.

Marengo JA, Jones R, Alves L, Valverde M. Future change of temperature and precipitation extremes in South America as derived from the PRECIS regional climate modeling system. international Journal of Climatology 2009; 29: 2241-2255.

Matthias, A. D.; Blackmer, A. M.; Bremner, J. M. A simple chamber technique for field measurement of emissions of nitrous oxide from soils. Journal of Environmental Quality, v. 9, n. 2, p. 251-256, 1980.

Menezes RSC, Sampaio EVSB; Giongo V and Perez-Biogeochemical cycling in terrestrial ecosystems of the CaatingaBiome.Braz. J. Biol.[online].2012, vol.72, n.3, suppl., pp. 643-653. ISSN 1519-6984.

MMA .Ministério do Meio Ambiente dos recursos hídricos e da Amazônia Legal. Primeiro relatório para a Convenção sobre Diversidade Biológica.1ªed. Brasília- DF. 1998. 63-87 p.

Ponce-Mendoza, A., Ceballos-Ramírez, J. M., Gutierrez-Micelli, F., & Dendooven, L. (2010).Emissionofnitrous oxide andcarbondioxidefromsemiarid tropical soils in Chiapas México.Revista Brasileira de Ciência do Solo, 34(5), 1617–1628. http://doi.org/10.1590/S0100-06832010000500015

Ripp, Jeffrey (Ed.). Analytical detection limit guidance & laboratory guide for determining method detection limits. Wisconsin Department of Natural Resources, Laboratory Certification Program, 1996. http://dnr.wi.gov/regulations/labcert/documents/guidance/-lodguide.pdf

Sousa-Neto ER. Fluxos de óxido nitroso (N2O), metano (CH4) e dióxido de carbono (CO2) a partir de um solo cultivado com cana-de-açúcar sob diversos tratos culturais. Centro de Energia Nuclear na Agricultura CENA. PhD. Universidade de São Paulo, Piracicaba, SP, 2012.

USDA- Agriculture and Forestry Greenhouse Gas Inventory: 1990-2005. Global Change Program Office, Office of the Chief Economist, U.S. Department of Agriculture. Technical Bulletin No. 1921. 161 pp. August, 2008. http://www.usda.gov/oce/global_change/AFGGInventory1990_2005.htm.