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Trace gas fluxes from intensively managed rice and soybean fields across three growing seasons in the brazilian amazon (1).

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ABSTRACT: The emission of gases that may potentially intensify the greenhouse effect has received special attention due to their ability to raise global temperatures and possibly modify conditions for life on earth. The objectives of this study were the quantification of trace gas flux (N_2O, CO_2 and CH_4) in soils of the lower Amazon basin that are planted with rice and soybean, and the relation of this flux to soil physical and chemical parameters and to precipitation. This study was conducted in agricultural fields planted with rice (*Oryza Sativa*) and soybean (*Glycine max*), located near the cities of Belterra and Santarém in western Pará State, Brazil, during the production years of 2005-2007. Measurements were done using static chambers in the field, and samples were analyzed by gas chromatography in the laboratory. Statistical analysis was conducted to determine variation in gas flux in the two crops, and the results show that CO_2 flux varied between 305 and 227 mg-C m^{-2} h^{-1} under rice, and 243 and 156 mg-C m^{-2} h^{-1} under soybean. Flux of nitrous oxide (N_2O) under rice varied between 4.5 and 20.4 µg-N m^{-2} h^{-1}, and under soybean flux variation was between 4.0 and 9.4 µg-N m^{-2} h^{-1}. Variation in flux of methane (CH_4) under rice was between 5.1 and 14.0 µg-C m^{-2} h^{-1}, and under soybean it was 0.4 and 1.2 µg-C m^{-2} h^{-1}. These results demonstrate that, during our study period, the rice crop had higher flux for all trace gases than the soybean crop.

Index Terms: Gas trace, crops, amazon region.

INTRODUÇÃO

Land use change, the anthropogenic clearing of forest for agriculture, and agricultural practices are three of the main contributors to the increase in atmospheric greenhouse gas (GHG) concentrations (Fearnside, 2005, IPCC, 2007) and thus climate change.

According to estimates of the Intergovernmental Panel on Climate Change (IPCC), the average global temperature will increase by 1.8 ºC by the end of this century (IPCC, 2007).

After land use change, agricultural practices such as soil tillage and application of mineral fertilizer affect soil gas emissions. Soil tillage accelerates decomposition of soil organic matter (SOM), whereas application of nitrogen-based fertilizer to the soil increases emissions of N_2O and NO (Crill et al., 2000; Steudler et al., 2002).

Due to recent agricultural expansion in the Amazon evaluation of impacts by this land use on greenhouse gas emissions has become a research priority. Many studies have documented the emissions from pastures (Cerri et al. 2006, Wick et al. 2005), and forests (Melillo, et al. 2001, Keller et al. 2005) but few studies have investigated emissions from croplands in the Amazon region.

In light of this situation, this work had as its principal objective the quantification of trace gas fluxes of N_2O, CO_2 and CH_4 in soils of the lower Amazon basin planted with soybean and rice, and the relation of this flux with soil chemical and physical parameters and also with precipitation.

MATERIAL E MÉTODOS

This study was conducted in agricultural fields planted rice (*Oryza sativa*) and soybean (*Glycine max*), located near the cities of Belterra and Santarém in western Pará State, Brazil, during the production years of 2005-2007.

The areas were initially planted with rice, then with soybean, both crops using a conventional management system, in the same area. During dry season this area was in fallow. The region's climate is type Am in the Köppen classification system (IBAMA, 2004), and the soils are predominately clayey Oxisols on slightly undulating terrain, classified by the Brazilian Soil Classification System as Typic Hapludox, with an average clay content above 850 g kg^{-1} (Rodrigues et al., 2001).

We sampled in two 1 ha monoculture fields of soybean and of rice. In each of the four fields 10 static chambers were randomly distributed for each sampling event. During the crop cycle (and concurrent with our sampling), mineral fertilizer was applied to both crops at a rate of 400 kg ha^{-1} (2 % N, 45 % P, and 60 % K), and nitrogen fertilizer was applied at a rate of 60 kg ha^{-1} of urea (60 % N) 60 days after plant emergence. Soybean productivity was 3,180 kg ha^{-1} (+- 400 kg) per year; rice productivity was 3,000 kg ha^{-1}.

Sampling was divided into three stages: Period 1: from initial seedling planting (day zero) to day seven, with daily sampling to verify the effects of fertilizer application; Period 2: day eight up to harvest day, with sampling conducted once a week; Period 3: harvest day to day 5 after harvest, with sampling done each day.

The static chamber method was used to sample N_2O and CH_4, following the protocol described in Keller et al. (2005).

Water filled pore space (WFPS) was calculated using Linn & Doran (1984) method.

Data analysis was done using the program Statistic 8.0 (Statsoft Inc.). Normality was tested, and when necessary data were log transformed (CO_2= log(CO_2); N_2O= log(N_2O+60), ; CH_4= log(CH_4+650), in mg m^{-2} h^{-1} (CO_2), µg m^{-2} h^{-1} (N_2O and CH_4), respectively. Differences were tested using one-way analysis of variance (ANOVA) and the Tukey post-hoc test. A probability level of $\alpha = 0.05$ was used for all tests. Linear regression was used to investigate possible relationships between soil moisture content and gas flux.

RESULTADOS E DISCUSSÃO

The high frequency of sample collection during the period of crop management was important to be able to evaluate the effects of rice and soybean crop systems on the emission of N_2O, because the soil preparation management in the soybean crop, together with high temperatures and rainfall, represent a unique situation to measure N_2O emission in the soil-atmosphere continuum.

With respect to N_2O flux, there was a significant difference in the soybean plantation in relation to period (F=10.4; $p<0.01$) and also for year (F=21.8; $p<0.01$), which could be explained by the greater availability of N in period 1 compared to the other periods. This greater availability of N is probably associated with good conditions for nitrifying and denitrifying bacterial activity (Firestone & Davidson, 1989) related to soil tilling under conventional management prior to seedling emergence that stimulates organic matter cycling, O_2, temperature, and moisture conditions (Dobbie & Smith, 2001) that favor N availability, which is reflected in greater N_2O emission (Table 3). These results are similar to those for young pastures in the Amazon rich in available N (Davidson et al. 2001). Greater availability of N and conditions of WFPS >60 % (Table 2) favor denitrifying bacterial activity in this system which should result in greater emission of N_2O (Davidson et al. 2001). This is one of the causes of the positive and significant relationship between N_2O e WFPS in the soybean crop. Anaerobic conditions associated with high concentrations of N, principally in the form of nitrate (N-NO_3^-) represent ideal conditions for high denitrifying bacterial activity, which could also explain the elevated flux found in period 1 in soybean in all the years studied.

In the present study, N_2O emissions from the soil under conventional agriculture increased with increasing WFPS, which is in agreement with other studies that report a greater denitrification rate in soils with higher water content (Bateman & Baggs, 2005; Liu et al., 2006). In the current study, when WFPS exceeded 50 % in this system N_2O emissions dramatically increased. This is consistent with the results from Keller et al. (2005) studying in primary forest in the Brazilian Amazon, and Palm et al. (2002) who found large increases in N_2O flux with a doubling or tripling of WFPS in soybean, rice, and corn cropping systems in the Peruvian Amazon. The transition point between the processes that operate aerobically (nitrification) and anaerobically (denitrification) is frequently cited as 60 % WFPS (Webb et al., 2010).

High mineral N availability could have been responsible for the high CO_2 flux in period 1 during N fertilization activities, as compared to CO_2 flux for all years (Table 1), fluxes that were much greater than those measured during other periods of cultivation. It is probable that fertilization had stimulated the absorption of N in the initial phase of soybean cultivation, and as a consequence, increased root and microbial respiratory activity. Carvalho (2005), demonstrate that N availability explained 66 % of the flux of CO_2 in savannah soils cultivated with corn under different management systems.

In period 2, compared to all 3 years, there were high fluxes of CO_2, just as in period 1. This pattern could be due to the growth cycle of soybean, being accelerated just after N fertilizer application, thus stimulating the autotrophic component of the soil and increasing soil CO_2 flux (Table 2). Additionally, the highest flux determined after soil preparation (Table 2) could be explained by the liberation of CO_2 previously produced through microbial action decomposing residual organic matter exposed by the physical fracturing of the soil or by root respiration (D'Andréa et al., 2006).

In 2007, CO_2 flux in period 1 was inferior compared to period 2, and although N fertilizer was applied in period 1, this difference could be in response to the limited addition of N associated with a smaller C:N of soluble material and also to the capacity of microbes to adapt to conditions of low availability of N. The high CO_2 flux values in period 2, when compared to the other periods could possibly be due to soil preparation during seedling planting. Various studies have attributed the increase in CO_2 flux during the initial phase of cultivation to the destruction of soil structure and the exposition of organic matter to microbial action.

The two biggest peaks of CH_4 flux during the rice crop cycle could be related to the availability of C for methanogenesis from residues from the previous crop, from production of organic matter by the growing crop itself, from soil organic matter, and from root exudates. Additionally, morphogenic changes in rice plants that occur in the final growth phase wherein plants reach the maximum number of tillers and panicles in the reproductive phase (Lindau et al., 1991), phases in which these peaks occurred. These results for methane production are similar to those found by Palm et al. (2002) studying in the Peruvian Amazon (range = 5.2 – 33 µg $m^{-2}.h^{-1}$ who attributed the positive flux of methane to high-input agricultural practices in a rice/soybean/corn system. Furthermore, these authors showed an inverse relationship with WFPS wherein the high-input agriculture system continued to produce methane even at just 45% WFPS. Interestingly, in the study by Palm et al. (2002) all the other treatments (low-input agriculture, shifiting cultivation, agroforestry, peach palm plantations, and forest fallow) had CH_4 consumption.

The pulse in the CH_4 flux in the rice crop in period 3 of 2005 (6.58 µg m^{-2}) is a significant result when compared to annual values reported for forests in the Amazon (-30 µg m^{-2}, Palm et al. (2002); -12.5 µg m^{-2}, Keller et al. (2005)), and this result could be due to the production of organic compounds from the anaerobic decomposition of organic matter such as leaves and dried panicules, and also to catabolism of labile organic compounds by methanogenic microbes, as well as to the increase in the exudation of organic compounds by roots, a process that increases as the plant develops. These exudates serve as substrate for methanogenic bacteria metabolism thus increasing the production of CH_4 (Aulakh et al., 2001). The increase of tillers and leaves, and consequently, the number of canals of escape of CH_4 from the soil through the plant, also could have contributed to the intensity of the first peak of CH_4 (0.44 µg m^{-2}) in period 2 of 2006 (Huang et al., 1997). This peak could also be related to the intense liberation of root exudates during the phases of panicule differentiation, booting stage, panicule emission, and finally, florescence in the reproductive phase of rice (Aulakh et al., 2001). With respect to the flux of N_2O, the low values registered in rice soils in period 3 of 2005, and compared with the 3 periods of 2007, could be related to a low availability of N and to aerobic conditions since WFPS was <60 % (Table 1). In general, Oxisols are characterized as being N-limited and present low nitrification rates, and only rarely the production of $N\text{-}NO_3^-$ exceeds the demand of microorganisms and roots. Eichner (1990) found N_2O emission rates in agricultural soils cultivated with leguminous plants to be between 0.34 and 4.6 kg N_2O-N ha.year^1. In the present study fluxes varied between 0.53kg ha year^1 and 0.90 kg N_2O-N ha year^1, values that are lower than 2.3 and 1.27 kg N_2O-N ha year^1 in high- and low-input annual soybean/rice/corn agricultural systems in the Peruvian Amazon (Palm et al., 2002). . Furthermore, in the rice crop there was a significant correlation between the flux of CO_2 and N_2O with WFPS ($p<0.05$), as reported by other authors (Keller et al., 2005; Weitz et al., 2001).

CONCLUSÕES

There was annual variation in the rice and soybean crops for carbon dioxide and nitrous oxide, but there was no variation for methane between crops.

There was positive and significant correlation between N_2O nitrous oxide and WFPS in the soybean crop.

During the period from initial seedling planting to day seven (period 1) the rice crop emitted more nitrous oxide than in the period from day eight up to harvest day or in the period from harvest day to 5 days after harvest the other two periods; in the soybean crop this happened more frequently in from harvest day to 5 days after harvest, (period 3).

In general the gas fluxes (carbon dioxide, nitrous oxide, and methane) were greater in the rice than the soybean crop.

REFERÊNCIAS

AULAKH, M. S.; WASSMANN, R.; RENNENBERG, H. Methane emissions from rice fields – quantification, mechanisms, role of management and mitigations options. Adv. Agron., 70:193-260, 2001

BATEMAN, E. J.; BAGGS, E. M. Contributions of nitrification and denitrification to N_2O emissions from soils at different water-filled pore space. Biol. Fert. Soils, 41:379-388, 2005

CARVALHO, A.M. Uso de plantas condicionadoras com incorporação e sem incorporação no solo: composição química e decomposição de resíduos vegetais; disponibilidade de fosforo e emissão de gases. Brasilia, Universidade de Brasilia, 2005. 167f. (Tese Doutorado)

CERRI, C. C.; CERRI, C. E. P. Agricultura e aquecimento global. Bol. Inf. Soc. Bras. Ci. Solo, Viçosa, MG, 32(1):40-44, 2007.

CRILL, P.M., KELLER, M.M., WEITZ, A., GRAUEL, B., VELDKAMP, E. Intensive field measurements of nitrous oxide emissions from a tropical agricultural soil. Glob. Biogeochem Cycles 14:85–95, 2000.

D'ANDRÉA, A. F.; SILVA, M. L.N.; SILVA, C. A. Emissões de CO_2 do solo: Métodos de avaliação e influência do uso da terra. In: ROSCOE, R.; MERCANTE, F. M.; SALTON, J. C., eds. Dinâmica da matéria orgânica do solo em sistemas conservacionistas: Modelagem matemática e métodos auxiliares. Dourados: Embrapa Agropecuária Oeste, 2006. Cap. 8, p. 199-242.

DAVIDSON, E. A., M. M. C. BUSTAMENTE, A. DE SIQUEIRA PINTO. Emissions of nitrous oxide from soils of native and exotic ecosystems of the Amazon and Cerrado regions of Brazil. Sci. World, 1(S2), 312 – 319, 2001.

DOBBIE, K. E.; SMITH, K. A. The effects of temperature, water-filled pore space and land use on N_2O emissions from an imperfectly drained gleysol. Eur. J. Soil Sci. 52(4):667-673, 2001.

EICHNER, M.J. Nitrous oxide emission from fertilized soils: summary of available data. J. Environ. Qual., 19: 272-280, 1990.

FEARNSIDE, P. M. Deforestation in Brazilian Amazonia: History, Rates, and Consequences. Conserv. Biol., Belo Horizonte, 19(4):680-688, 2005

FIRESTONE, M.K. ; DAVIDSON, E.A. Microbilogical basis of NO and N_2O production and cosumption in soil. In: ANDREAE, M. O.; SCHIMEL, D.S., eds.) Exchange of trace gases between terrestrial ecosystems and yhe atmosphere, Berlin: Jonh Wiley & Sons, 1989. p. 7-21.

HUANG, Y.; SASS, R.L.; FISHER, Jr. F.M. Methane emission from Texas rice paddy soils. 2. Seasonal contribution of rice biomass production to CH_4 emission. Glob. Chang. Biol., 3(6):491-500, 1997.

INSTITUTO BRASILEIRO DO MEIO AMBIENTE E DOS RECURSOS NATURAIS RENOVÁVEIS-IBAMA. Floresta Nacional do Tapajós - Plano de Manejo. IBAMA, Belterra, Pará. 2004. 373p.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE - IPCC. The physical Science basis: contribution on working group I to the fourth assessment report of the intergovernmental Panel on Climate Change. Paris, 2007.

KELLER, M.; VARNER, R.; DIAS, J. D.; SILVA, H.; CRILL, P.; OLIVEIRA JUNIOR, R. C. & ASNER, G. P. Soil-atmosphere exchange of nitrous oxide, nitric oxide, methane, and carbon dioxide in looged and undisturbed forest in the Tapajos National Forest, Brazil. Earth Interact., 9:1-28, 2005.

LINDAU, C.W. & BOLLICH, P. K. Effects of urea fertilizer and environmental factors on CH4 emissions from Louisiana, USA rice field. Plant Soil, 136(2):195-203, 1991.

LINN, D. M. & DORAN, J. W. Effects of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and no tilled soil. Soil Sci. Soc. Am. J., 48:1267-1272, 1984.

LIU, X. J.; MOSIER, A. R.; HALVORSON, A. D. & ZHANG, F. S. The impact of nitrogen placement and tillage on NO, N_2O, CH_4 and CO_2 fluxes from a clay loam soil. Plant Soil, 280:177-188, 2006.

Melillo, J. M., P. A. Steudler, B. J. Feigl, C. Neill, D. Garcia, M. C. Piccolo, C. C. Cerri, *and* H. Tian. Nitrous oxide emissions from forests and pastures of various ages in the Brazilian Amazon, J. Geophys. Res., 106(D24), 34179–34188, *doi:*10.1029/2000JD000036. *2001.*

PALM, C. A., J. C. ALEGRE, L. AREVALO, P. K. MUTUO, A. R. MOSIER, R. COE. Nitrous oxide and methane fluxes in six different land use systems in the Peruvian Amazon. Global Biogeochem. Cycles, 16(4), 1073, doi:10.1029/2001GB001855. 2002.

RODRIGUES, T. E.; SANTOS, P. L. ; OLIVEIRA JUNIOR, R. C. ; VALENTE, M. A. ; SILVA, J. M. L. ; CARDOSO JUNIOR, E. Q. . Caracterização dos Solos da Área do Planalto de Belterra, Município de Santarém, Estado do Pará. Documentos. Embrapa Amazônia Oriental, Belém, Pará, 115:01-55, 2001.

STEUDLER, P.A., GARCIA-MONTIEL, D.C., PICCOLO, M.C., NEILL, C., MELILLO, J.M., FEIGL, B.J. & CERRI, C.C. Trace gas responses of tropical forest and pasture soils to N and P fertilization. Global Biogeochem Cycles 16(7):1–12, 2002. DOI 10.1029/2001GB001394

WEBB, J.; PAIN, B.; BITTMAN, S. & MORGAN, J. The impacts of manure application methods on emissions of ammonia, nitrous oxide and on crop response - A review. Agric. Ecosyst. Environ., 137:39-46, 2010.

WEITZ, A. M.; LINDER, E.; FROLKING, S.; CRILL, P. M. & KELLER, M. N_2O emissions from humid tropical agricultural soils: effects of soil moisture, texture and nitrogen availability. Soil Biol. Biochem., 33:1077-1093, 2001.

WICK, B.; VELDKAMP, E.; MELLO, W.Z.; KELLER, M.; CRILL, P. Nitrous oxide fluxes and nitrogen cycling along a pasture chronosequence in Central Amazonia, Brazil. Biogeosciences Discussions, v.2, p.499-535. 2005.

Table 3. Average trace gas (N_2O, CO_2 and CH_4) flux values and the respective WFPS values (%) with standard error of the mean (±SEM) for years 2005 to 2007 in an area of mechanized cultivation of soybean and rice.

Crop	**Period** (years)	**CO_2** mg-C m^{-2} d^{-1}	**N_2O** µg.m^{-2}	**CH_4** µg.m^{-2}	**WFPS** %
Rice	**2005**	443.9±30.6 **a**	38.0±9.2 **a**	-0.006±0.7 **a**	39.2±1.6 **a**
	2006	197.5±23.2 **b**	7.0±0.9 **b**	-0.6±0.8 **a**	60.3±1.4 **b**
	2007	310.8±24.4 **c**	3.2±0,5 **b**	-3.0±4.3 **a**	55.5±1.0 b
Soybean	**2005**	305.1±32.2 **a**	1.8±0.4 **a**	-0.5±0.2 **a**	62.3±0.6 **a**
	2006	166.8±15.0 **b**	7.5±1.3 a	-0.6±0.3 **a**	40.4±1.4 **b**
	2007	254.1±22.5 **ab**	6.6±11.5 **a**	0.3±0.3 **a**	29.0±1.2 **c**

* -Different letters in the same columns and crop represent statistically significant differences (Tukey, $p<0,05$).

Table 2. Average flux of N_2O, CO_2 and CH_4 and the standard error of the mean (±SEM) for the years 2005-2007 in mechanized soybean and rice fields. The periods (1, 2, and 3) represent cultivation phases.

Year	**Treatment**	**N_2O ± SEM** µg-N m^{-2} h^{-1}	**CO_2 ± SEM** mg-C m^{-2} h^{-1}	**CH_4 ± SEM** µg-C m^{-2} h^{-1}	WFPS %
			Soybean		
2005	**Period 1**	1.9 ± 0.5	500± 57	-0.2 ± 0.3	60.6±0.9
	Period 2	1.6 ± 0.4	131 ± 15	-0.8 ± 0.4	64.0±1.0
	Period 3	2.6 ± 2.8	120 ± 34	-0.2 ± 0.7	62.8±1.3
2006	**Period 1**	7.4 ± 2.3	178 ± 22	-0.1 ± 0.4	47.1±1.9
	Period 2	7.9 ± 1.0	155 ± 24	-1.3 ± 0.7	32.8±1.8
	Period 3	6.2 ± 1.6	143 ± 24	-0.5 ± 0.1	28.3±5.6
2007	**Period 1**	3.6 ± 0.9	104 ± 13	0.5 ± 2.9	22.6±2.0
	Period 2	2.6 ± 0.7	407 ± 36	0.1 ± 2.5	31.1±1.3
	Period 3	21.5 ± 3.3	122 ± 18	0.6 ± 5.6	34.2±3.7
			Rice		
2005	**Period 1**	77.8±18.8	350 ± 32	-1,0 ± 0.4	35.0±2.1
	Period 2	5.3 ± 2.0	607 ± 54	-0.8 ± 0.9	43.0±2.7
	Period 3	1.8 ± 0.8	205 ± 17	6.6 ± 4.7	41.8±5.3
2006	**Period 1**	8.2 ± 1.6	135 ± 12	-1.2 ± 1.4	46.4±2.1
	Period 2	6.7 ± 1.4	245 ± 44	0.4 ± 0.3	69.3±2.1
	Period 3	5.8 ± 2.1	181 ± 41	-1.9 ± 2.9	60.2±1.3
2007	**Period 1**	3.3 ± 1.1	180 ± 22	-8.6 ± 12.3	51.2±1.4
	Period 2	3.4 ± 0.8	350 ± 45.3	0.1 ± 2.6	55.2±2.0
	Period 3	2.9 ± 0.6	427 ± 48.8	0.04 ± 2.0	61.6±1.1