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Methane emission from tropical savanna *Trachypogon sp.* grasses

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Abstract. Methane flux measurements from the soil-grass system were made during the wet season in unperturbed plots and plots where standing dry and green *Trachypogon sp.* grasses were clipped to just above the soil surface. Results support the surprising discovery that vegetation emits methane. The results of this work allows to infer that the savanna dry/green mixture of grasses produce methane at a rate of $\sim$10 ng m^{-2} s^{-1}, which is in agreement with early published soil-grass system fluxes. An extrapolation of this flux to the global savanna produces an annual emission much lower than the CH_4 production recently suggested in the literature. On the other hand, during the wet season savanna soil consume CH_4 at a rate of $\sim$4.7 ng m^{-2} s^{-1}. Therefore, the tropical savanna soil-grass system would make a modest contribution to the global budget of methane.

1 Introduction

Methane is an important greenhouse gas, whose radiative forcing (1750–1998) has been estimated to be 0.48 Wm^{-2}, $\sim$20% of the total positive forcing produced by long lived gases and tropospheric ozone (Ramaswamy et al., 2001). The methane budget (sources and sinks) was believed to be relatively well known, however, recently a surprising discovery, based on laboratory measurements, indicated that land plants would emit methane in significant quantities, up to 30% of the present evaluated global sources (Keppler et al., 2006); however, Kirschbaum et al. (2006), using the same basic CH_4 flux information produced by Keppler et al. (2006), presented alternative extrapolations, which indicate much lover global plant CH_4 emissions. Methane emissions from vegetation may explain early field results from tropical ecosystems (Crutzen et al., 2006) and recent satellite observations (Frankenberg et al., 2005). In the past, erratic and sometimes confusing results were obtained in studies of CH_4 soil fluxes in the Venezuelan savanna region (Hao et al., 1988; Scharffe et al., 1990; Sanhueza et al., 1994a). On average a net emission of methane was reported, however, quite often consumptions from individual plots were registered. According to Sanhueza et al. (1994a), these results are in contrast to the general belief that non-flooded soils of temperate, subtropical, and tropical regions only act as sinks for atmospheric methane. The authors speculated that, by an unknown mechanism, the methane emitted in the Venezuelan savannah region could be produced by biogenic activity. Now, after publication of the Keppler et al. (2006) paper, showing that both living plants and plant detritus produce methane, it is clear that the soil-grass system is more complex than previously believed. In addition to soil processes (e.g., population of methylotrophic bacteria) other aspects (e.g., presence of living or dead plants) must be taken into consideration, to understand/explain the CH_4 flux variability. In this paper we report a study of the soil-grass system in the central savanna region of Venezuela, made in 1990, which allows to infer the role of grasses in the fluxes of CH_4 from the soil-grass system.

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2 Field measurements

The study was performed during the 1990 wet season at the Estación Biológica de los Llanos, located in the central part of the Venezuelan savannah climatic region (8°53′ N; 67°19′ W). Two well defined climatic periods occur in the area: a dry season from December to April and a rainy season from May to November. The annual rainfall is 1300 mm and the annual mean temperature is 27.6°C. Soils are acidic, with a low rate of mineralization and poor in nutrients. They support graminea grasses (mainly *Trachypogon sp*. and *Axonopus canescens*) interrupted by trees and scrub (*Curatella*

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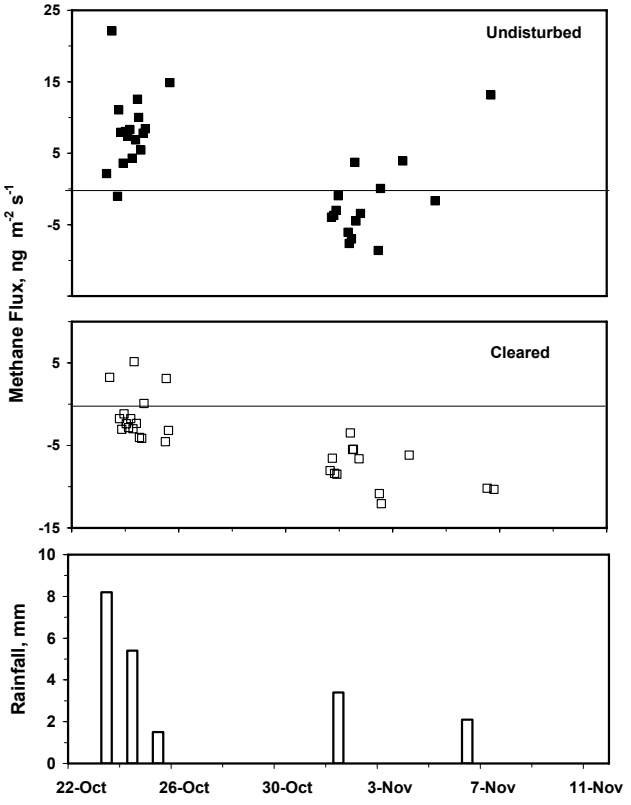

Fig. 1. Methane fluxes from undisturbed and cleared plots. Two points over 25 ng m^{-2} s^{-1} from undisturbed plots in October are not shown. The amount of rainfall is also given.

americana, *Boudichia virgilioides* and *Byrsonima crassifolia*). Physical and chemical properties of the soils, obtained from soil samples of 10 cm depth, were given by Sanhueza et al. (1994b).

Fluxes from the soil-grasses system were measured using the enclosed chamber technique; the stainless steel glass chamber and other details were similar to those described by Conrad and Seiler (1985). During measurements the chamber was covered with aluminum foil. CH_4 was analyzed by gas chromatography, using a flame ionization detector. Other experimental/analytical details are given by Scharffe et al. (1990). Gas samples were automatically supplied to the chromatograph injection valve and re-circulated back to the chamber at a flow rate of 250 mL min^{-1}. The gas stream passed through a cold trap at 78°C to remove water.

A particular plot was measured for ∼60 min, during which the following samples were injected to the gas chromatograph: one sample of ambient air, seven samples from the chamber (1 every 6 min), and two samples of calibration gas. To initiate measurements, the chamber was placed manually over the frame; after measurements were made the chamber was moved to another frame and the process repeated. Most experiments show that after the chamber was closed, variations (increase or decrease) in the concentration were observed. After a relatively short period, changes in concentrations decline and fluxes (emission or consumption) were calculated using only the fourth initial points of a particular run. Gravimetric soil moistures were measured in samples of 2 cm depth. Soil temperature at 1 cm depth was recorded continuously during flux measurements with a thermocouple.

3 Results

Methane flux measurements were made in four unperturbed plots and three plots where standing grasses were clipped to just above the soil surface and plant litter removed from the soil surface (cleared plots). In the unperturbed plots there was a representative amount of *Trachypogon sp* grasses, which is the most abundant natural grass in the region. Since the study was made in an area which was not burned the previous dry season, dry dead standing grasses were mixed with green ones; in average 46% (dry weight) was dry grass.

Individual flux measurements are shown in Fig. 1. In the figure is also indicated the rainfall that occurred during the measurement period; average soil moistures during the rainy days (23–26 October) was ∼8% and ∼3% during the less rainy period (1–7 November). Under this soil moisture conditions there should not be any gas transport limitation between atmospheric CH_4 and the soil bacteria (Striegl, 1993; Castro et al., 1995). During both periods (rainy and less rainy) measurements were made at the same 4 unperturbed and 3 cleared plots.

In unperturbed plots (Fig. 1a) fluxes produce during the 23–26 October period were quite different than the ones observed during the 1–7 November period. This is not surprising considering that the soil-grass system is quite complicate. CH_4 consumption by soils would depend on soil moisture and soil temperature (Castro et al., 1995; Hanson and Hanson, 1996), on the other hand, CH_4 production by plants would depend on ambient temperatures and solar irradiation (Keppler et al., 2006), and also if plant are live or dead. It seems that soil and ambient conditions during the 1–7 November period favor CH_4 soil consumption, whereas conditions in the 23–26 October period seems to favor methane emission from the soil-grass system; e.g., clearly soil consumption is lower than the one observed in the November period (Fig. 1, cleared plots). CH_4 fluxes plotted as a function of soil temperatures are shown in Fig. 2. In general, in the undisturbed plots (Fig. 2a) methane emission was observed at temperatures lower than ∼30°C, whereas consumption was recorded at higher temperature. This could mean that at high temperatures live grasses decrease the production of methane (likely due to physiological stress) and/or that the bacteria activity, which consumes methane, increases. According to Hanson and Hanson (1996) different soils exhibit different methane oxidation responses with respect to temperature, indicating that populations of methanotrophs in nature could adapt to different temperatures; methane

Table 1. Methane fluxes from the soil-grass system in the tropical savanna.

Location	Type of grass	Flux ($ng\,m^{-2}\,s^{-1}$)		Reference
		Dry season	Wet season	
Calabozo, Natural savanna	*Trachypogon sp*.		6.0 (−8 to 44)[a] SM[b]: 3–8%	This work
Calabozo Managed savanna	Mixed, mainly *Trachypogon sp*.	10.6 (2 to 15)[a] SM: 1–10%		Sanhueza et al. (1992)
Chaguarama, Natural savanna	*Trachypogon sp*.	11.4 (0.5 to 27)[a] SM: <1%		Hao et al. (1988)
Guri, Natural savanna	Mixed, mainly *Trachypogon sp*.		9.3 (−2.6 to 23)[a] SM: 5–40%	Scharffe et al. (1990)
South Africa Natural savanna	*Hypertelia dissoluta; Elionurus argenteus; Hyparrhenia hirta*	∼5 SM: low		Zepp et al. (1996)

[a]average (range); [b]soil moisture

consumption in cleared soil (Fig. 2b) presents a weak positive correlation with soil temperature, similarly to findings of Koschorreck and Conrad (1993) in different German soils.

In their natural environment, savanna aerated soils continuously change from "wet" and "dry" conditions, which in turn conditions soil and near surface temperatures. Therefore, in spite of the differences between the two periods, we average over all the data to obtain a representative value for the natural savannah grass system. In that way, the averaged flux for the unperturbed plots shows a net production of methane from the soil-grass system of $6.0\,ng\,m^{-2}\,s^{-1}$, and a standard error of $2.0\,ng\,m^{-2}\,s^{-1}$ (n=34); this result is in agreement with published data summarized in Table 1. On the other hand, as presented in Fig. 1b, the perturbed-cleared plots showed a clear consumption of CH_4 with an average of $-4.7\,ng\,m^{-2}\,s^{-1}$ and a standard error of $0.9\,ng\,m^{-2}\,s^{-1}$ (n=30). A t-test analysis of the data indicates that the two sets (undisturbed and cleared plots) are statistically different, whether we include all the data together or the two groups separately, with an α value of 0.05 (95% significance); a summary of the statistical results is given in Table 2. During the 1–7 November period, the average flux from undisturbed plots is significantly different than the one from cleared plots, indicating that grasses emit methane compensating for soil consumption. Therefore, under regular field conditions, on average, the soil-grass system emits CH_4, most likely due to methane production from grasses, supporting the surprising discovery by Keppler et al. (2006) that vegetation emits methane. Cleared savanna soils consume methane, most likely due to the activity of methylotrophic bacteria in aerated soils (Conrad, 1996; Hanson and Hanson, 1996).

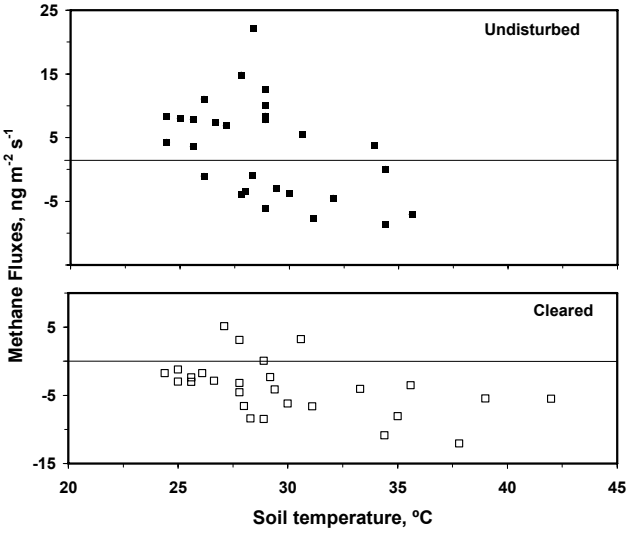

Fig. 2. Methane fluxes as a function of soil temperature in both undisturbed and cleared plots.

In the laboratory experiments described by Keppler et al. (2006), the exposition of living or dead plants to solar radiation induced a large increase of the emission of methane, which continued for a relatively long period of time (∼15 min) after the light was switched off. As mentioned, in our field CH_4-flux measurements, plants or detritus present in the experimental plots were exposed to the sun light until the chamber was set in position and the fluxes were calculated using the firsts four time points (less than 15 min). However, since emissions from plants are not well

Table 2. t-Test (α=0.05) to compare undisturbed and cleared conditions measurements.

Period	Average ($ng\,m^{-2}\,s^{-1}$)	Variance	n	Exp. t	Critical t (two tails)	Probability[a]
Both periods:				−7.4	2.0	3×10^{-9}
Undisturbed	6.0	145	34			
Cleared	−4.7	22	30			
Oct period:				−6.7	2.1	2×10^{-6}
Undisturbed	12	152	19			
Cleared	−1.4	8.3	16			
Nov period:				−7.7	2.1	9×10^{-8}
Undisturbed	−2.0	31	15			
Cleared	−8.5	11	14			

[a]Low probabilities indicate that the two groups of data are significant different.

understood we do not know what sort of response would be found if samples were illuminated with sunlight during flux measurements.

4 Discussion

4.1 Methane consumption by savanna soils

The results from the cleared plots indicate that savanna soils consume methane under wet season conditions. The clearance of the savanna soil surface (grasses and litter) by burning also produces a significant reduction of the methane production from the soil-grass system (Poth et al., 1995; Zepp et al., 1996). Actually, at the cerrado site in Brazil, the burned soils consume methane, whereas the unperturbed soils produce CH_4 (Poth et al., 1995), in good agreement with our clearing experiment at the Calabozo site.

The consumption rate of $-4.7\,ng\,m^{-2}\,s^{-1}$ obtained in this work, during the wet season, is in the range of consumptions reported by Seiler et al. (1984) in soils of a broad-leafed savanna in South Africa. On the other hand, evidence under very dry conditions (Hao et al., 1988; Zepp et al., 1996) suggests that the consumption of atmospheric methane by savanna soils would be negligible during the dry season, most likely due to an inhibition of the soil microbial processes under dry conditions. Extrapolating the wet season (7 months) consumption rate, to the world savanna, produces a soil savanna sink of methane of $\sim1.3\,Tg\,yr^{-1}$.

4.2 Methane production by savanna grasses

Emission of methane from tropical savanna soils have been reported at sites in Venezuela (Hao et al., 1988; Scharffe et al., 1990; Sanhueza et al., 1992), Brazil (Poth et al., 1995) and South Africa (Zepp et al., 1996), which now should be interpreted as fluxes from the soil-grass system. Table 1 presents a summary of fluxes from the soil-grass system reported in the literature, which are in relatively good agreement with the emissions rates observed in this work. The scarce data suggest that higher amounts of CH_4 are produced during the dry season; in this case the production of methane should be less compensate by soil consumption.

The average fluxes obtained in this work from unperturbed ($6.0\,ng\,m^{-2}\,s^{-1}$) and cleared ($-4.7\,ng\,m^{-2}\,s^{-1}$) plots indicate that the mixture of green and dry *Trachypogon sp.* grasses produce methane at a rate of $10.7\,ng\,m^{-2}\,s^{-1}$, during the wet season; fluxes from the soil-grass system measured at the Guri site (see Table 1) suggest a slightly higher production of methane ($\sim14\,ng\,m^{-2}\,s^{-1}$) from grasses. On the other hand, using the fluxes obtained during the dry season at the Chaguarama and Calabozo sites (see Table 1), and assuming negligible methane soil consumption under very dry soil conditions, a production of methane of $\sim10\,ng\,m^{-2}\,s^{-1}$ from grasses is derived. Therefore, assuming similar emissions ($\sim10\,ng\,m^{-2}\,s^{-1}$) during dry and wet seasons and that this flux is representative of the world savannas, with a total area of $15\times10^6\,km^2$, a global emission of methane from savanna grasses (green plus dry) of $\sim5\,Tg\,yr^{-1}$ is estimated. This annual emission is higher than the value given by Keppler et al. (2006) for tropical savanna and grassland leaf litter (mean: $1\,Tg\,yr^{-1}$), but lower than the one for living biomass (mean: $29.2\,Tg\,yr^{-1}$); however, it is in the same range than the global savanna extrapolation ($2.2–6.6\,Tg\,yr^{-1}$) reported by Kirschbaum et al. (2006).

In conclusion, our results suggest that savanna grasses make a modest contribution to the global emission of methane (∼1%), which is in part compensated by soil consumption during the wet season. The low production of methane from tropical savanna grasses is in agreement with results obtained at temperate grasslands (Mosier et al., 1991, 1997) and tropical pastures (Keller and Reiners, 1994; Mosier and Delgado, 1997). Those studies found that the soil-grass system of these ecosystems consumes methane.

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