

METHANE EMISSIONS FROM A FLOODED RICE FIELD IN THE SOUTH OF BRAZIL

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ABSTRACT

The State of Rio Grande do Sul in Brazil cultivates about 1Mha of rice in paddy fields. The soils are prepared using either conventional tillage (CT, 41% of the area) or no tillage (NT, 14% of area), the remaining falling in a mixed soil-preparation category. The outcomes of the current study represent the first evaluation of CH₄ emissions from flooded rice fields in the south of Brazil. This information will feed the Brazilian greenhouse gas inventory. The study was carried out from January through March 2003 at the IRGA experimental station located in the municipality of Cachoeirinha, Rio Grande do Sul, Brazil. Rice has been cultivated in this Gleisol area since 1994 using either the CT or NT system. The closed chamber method was used to collect air samples from 9:00 AM to 12:00 Noon on a weekly basis or in 24-hour campaigns; samples were analyzed using gas chromatography. Soil and plant parameters were also measured in order to determine which ecosystem factors affect CH₄ emissions from the soil into the atmosphere.

Along the period, CH₄ emission rates varied from 24 to 703 mg m⁻² day⁻¹. NT plot emissions were initially greater than those from the CT plot, probably due to having maintained the crop residues on the surface of soil in the NT system. Nevertheless, CH₄ emission rates in the CT plot were higher than in the NT plot 14 days after flooding, probably due to the higher root mass in the deeper soil layer in the NT system. The close relationship (P<0.01) found between CH₄ emissions and soil temperature in both systems explains 60% of CH₄ emissions. Total CH₄ emissions were 33 and 22 g m⁻² in the CT and NT systems, respectively. The emission variation between the soil preparation systems corresponds to 2,860 kg ha⁻¹ CO₂ equivalents. Moreover, this reduction represents 0.8 Mg ha⁻¹ yr⁻¹ C equivalents, greater than the average value of 0.58 Mg C ha⁻¹ year⁻¹ for C sequestration in agricultural soils in the subtropical region of Brazil. The 24-hour campaign emissions produced a sigmoid curve into both the atmosphere and the chamber, albeit with an inverse relationship. The 24-hour emissions were controlled by the soil and flood-water temperatures.

1.0. INTRODUCTION

Irrigated rice farming in paddy fields is an important anthropogenic source of CH₄ amenable to management for the purpose of mitigating emissions (Sass *et al.*, 1994). In Brazil, irrigated rice agriculture is mostly restricted to the State of Rio Grande do Sul (RS), where rice farming extends over approximately 1Mha. More than 50% of the domestic rice production comes from Rio Grande do Sul (IRGA, 2003).

The most frequently used soil preparation systems in Rio Grande do Sul are conventional tillage (CT) and no tillage (NT), which represent 41% and 14% of the cropped area, respectively (IRGA, 2003). In the CT system, the soil is disk- and plough-tilled (0-0.2 m) and the surface residues shredded and incorporated into the soil. In the NT system, the soil is not tilled and only a ridge is made for drilling. In addition, residues are not shredded, but maintained whole over the soil surface. The differences between the two soil preparation systems may influence CH₄ emissions into the soil-atmosphere system.

In Brazil, *in situ* evaluations of CH₄ emissions in irrigated rice crops were begun only recently. The objectives of this study are to (i) evaluate CH₄ emissions in irrigated rice farming operations, under both the CT and NT soil preparation systems in southern Brazil and their relation with environmental factors and (ii) to evaluate CH₄ emissions in 24-hour campaigns.

2.0. METHODOLOGY

The work was coordinated by the National Research Center for Environmental Impact Monitoring and Evaluation (CNPMA) of the Brazilian Agricultural Research Corporation (EMBRAPA), located in Jaguariúna, in the State of São Paulo, with the participation of the Federal University of Rio Grande do Sul (UFRGS) and the Rio Grande do Sul Rice Institute (IRGA). The field experiments, which were carried out on a gleysol with loamy texture (EMBRAPA, 1999), have been conducted at the IRGA Experimental Station (29°57'02" S and 51°06'02" W), in the municipality of Cachoeirinha, State of Rio Grande do Sul, since 1994. The climate is Cfa – humid subtropical, according to Köppen's classification. The average annual historical (1975-2002) mean air temperature is 20° C, while average rainfall is 1,375mm (FEPAGRO, 2003). Rice (IRGA 422 CL variety) was in-line sown using machinery on 10 December 2002 and final paddy flooding accomplished by 30 December 2002. When air sampling began, soil (systems average and 0-0.2 m) pH in water (1:1) was 5.2, with 9.5 g kg⁻¹ of organic carbon; 0.95 g kg⁻¹ of total N; 6.4 cmol_c L⁻¹ of CTC; and 47% of base saturation.

The close chamber method was used for the weekly air samples. The procedures were based on the Global Standardized Measurement proposal for CH₄ emissions, coordinated by the Rice Cultivation and Gas Flow Committee (RICE). On day 7 after flooding (DAF), two bases (0.05 m deep) were set up in each cropping system, which remained fixed during the entire evaluation period. The first data collection was carried out on DAF 8 and the last on DAF 105. Air samples were always taken beginning at 9:00 AM, starting with the CT chambers and ending with the NT chambers. At the time of each collection, atmospheric air and soil (at 0.02, 0.05 and 0.1 m depths) temperatures were recorded, and soil solution samples made at 0.05 m in depth. Three 24-hour campaigns were carried out: the 1st and 3rd collections in the CT plot and the 2nd collection in the NT plot. A three-hour interval was

observed between collections. The air samples were analyzed at the CNPMA laboratory by means of gas chromatography with a megabore column (0.53 μm , 30m) and a flame ionization detector. The mineral N (Kjeldahl) and organic C (automatic analyzer) contents of the soil solution samples were quantified at the UFRGS Environmental Biochemistry Laboratory. The climatic information was obtained at the IRGA meteorological station.

3.0. RESULTS AND DISCUSSION

3.1. MAIN CAMPAIGNS

During air sampling, average solar radiation was $440\text{cal cm}^{-2}\text{ day}^{-1}$; mean monthly rainfall, 179 mm; and mean minimum, mean and maximum temperatures, 18° , 25° and 33°C , respectively.

Along the cultivation period, CH_4 emission rates in the NT plot were lower than in the CT plot, except for the two first data collections (Figure 1). The average CH_4 emission rates and amplitudes were 290 and $670\text{ mg m}^{-2}\text{ day}^{-1}$ in the CT plot and 212 and $450\text{ mg m}^{-2}\text{ day}^{-1}$ in the NT plot. The average rate between the systems was $251\text{ mg m}^{-2}\text{ day}^{-1}$, which falls within the emission interval cited in the international literature, namely, from 0 to $1920\text{ mg m}^{-2}\text{ day}^{-1}$ (Le Mer & Roger, 2001).

The higher initial CH_4 emission in the NT plot could be due to having kept the winter crop residues on the soil. Sousa (2001), working with two soils and using rye-grass residues incorporated to or spread over the soil, showed increased production of organic acids during the first weeks of soil flooding when the rye-grass residues remain on the soil surface. In that experiment, the highest concentration found in the soil solution were of acetic acid, a product of the anaerobic decomposition of organic residues, which is readily used in methane production (Wassmann *et al.*, 1998). Organic plant residues in flooded soils increase CH_4 emissions by reducing the oxidation-reduction potential (Eh) of the soil and serving as a source of organic compounds to the methane production (Neue *et al.*, 1996).

In the CT plot, residue decomposition may have occurred prior to total flooding, because of the increase in the total specific surface area (SSA) of the shredded residues susceptible to microbial action. Since the residues were partially decayed when the flooding process began, it would take longer to attain the reduction levels required for methane production in the CT plot than in the NT plot. During the cultivation period, however, the increased SSA could result in increased decomposition of the more recalcitrant plant residue fractions in the CT plot than in the NT plot, where the plant residues were not shredded and, therefore, were less susceptible to microbial attack.

The deeper roots trend in the CT soil profile (data not presented), when compared with the NT plot, could explain the greater CH_4 emissions. In deeper soil layers, less O_2 is available and, consequently, the environment is more reduced. Under such conditions, in the presence of labile CO, the CH_4 production potential would be greater (Wassmann *et al.*, 1998). The more superficial root trend in the NT plot could cause an Eh that hinders methane production. During the cultivation period, the CT plot always had more aerial plant mass than the NT plot. Increased plant mass could be associated with an expanded root system, and a possible increased release of C by the roots, enhancing CH_4 production (Wang *et al.*, 1997).

Emission peaks occurred in both cultivation systems, On DAF 35 (end of the vegetative stage) and on DAF 66 (end of the reproductive phase/

beginning of the ripening phase), also obtained by Lindau *et al.* (1991). The first peak may have been due to the release of organic compounds from decaying winter plant-cover residues, allied to the presence of easily metabolized compounds in the organic matter of the soil (Neue *et al.*, 1996). The second peak could be related to the release of root exudates, in addition to rice root decomposition. In the present study, N fertilization (N1, Figure 1) was carried out two days prior to the peak detected on DAF 35, and this could have influenced the size of the peak in both soil preparation systems. Cai *et al.* (1997) recorded 7% and 14% decreases in CH₄ emissions with the application of 100 and 300 kg N ha⁻¹, respectively, when compared with the control plot. Lindau *et al.* (1991), however, showed that urea fertilization increased CH₄ emissions by 86% with the application of 300 kg N ha⁻¹ when compared with the control plot.

In both management systems, CH₄ emissions during the cultivation period were associated with the average soil temperature ($P < 0.01$) (Figure 2), which explains the 60% variation in the emissions. Methane emissions increased by 45 mg m⁻² day⁻¹ for every one-degree rise in soil temperature. This is due to increased microbial decomposition of the organic matter and residues added to the soil, via substrate control of the methane producing bacteria and increased bacterial activity (Schimel *et al.*, 1993).

Soil drainage enhanced the decreasing CH₄-emission trend in both management systems, with final values of 33 mg m⁻² day⁻¹ in the CT plot and 24 mg m⁻² day⁻¹ in the NT plot. This was attributed to decreased soil moisture after drainage (Bronson *et al.*, 1997), which increased soil oxidation and reduced methane-production activities (Le Mer & Roger, 2001).

The total amount of CH₄ released during the 98-day period was 33% higher in the CT plot (33 g m⁻²) than in the NT plot (22 g m⁻²). This lowest CH₄ emission rate in the NT system represents 2,860 kg ha⁻¹ CO₂ equivalents not released into the atmosphere, reducing the participation of NT systems in the anthropogenic greenhouse effect.

These findings derive from pioneering work in southern Brazil and will be used to improve the national inventory of greenhouse gas emissions from agricultural activities, reducing, thus, current uncertainties.

3.2. 24-HOUR CAMPAIGNS

In the first evaluation, the average air, flood water and soil temperatures were relatively higher than in the last two evaluations. In the latter, the temperatures were practically the same (Table 1).

Table 1. Stage of development of the rice plants and atmospheric air, flood-water and soil temperatures (0.02, 0.05 and 0.1 m depths) in 24-hour collections in CT and NT plots. IRGA, Cachoeirinha, Rio Grande do Sul, Brazil.

Collection	System	Date	Stage	Temperature, ° C				
				Air	Water	Soil, m		
						0.02	0.05	0.10
1	PC	24-25 Fev.	DPP ¹	26.4	24.7	23.8	23.7	23.6
2	PD	17-18 March	Pasty grain	22.8	21.2	21.5	21.7	21.9
3	PC	31 March-1 st April	Ripening	21.4	22.2	21.8	21.8	21.8

¹ Beginning of panicle differentiation.

In the first collection, the adjustment of the data resulted in a sigmoid curve for the atmospheric CH₄ concentration near the chamber (2 m from the ground) and for CH₄ emissions in the chamber (Figure 3). Nevertheless, an inverse relationship was found between the curves. The former showed the minimum point between 12:00 Noon and 3:00 PM on DAF 24 and the maximum point between 3:00 and 6:00 AM on DAF 25, while for the CH₄-cam emissions the maximum point fell between 12:00 Noon and 3:00 PM of DAF 24 and the minimum point, between 3:00 and 6:00 PM on DAF 25.

Variations in atmospheric conditions from daytime to nighttime affect atmospheric CH₄ concentrations near the flood-water surface. During the day, solar radiation increases the air temperature, reducing the relative humidity and air density, and enabling the CH₄ to rise into the atmosphere. The formation of a atmospheric CH₄ concentration gradient near the water surface can help CH₄ transportation to the higher layers of the atmosphere. The phenomenon is based on increased daytime emissions and, therefore, increased atmospheric CH₄ concentrations near the flood-water surface, causing a concentration gradient and generating diffusive processes for the purpose of eliminating it (Harrison & De Mora, 1996).

In the small hours, however, low temperatures and high relative humidity rates lead to the accumulation of CH₄ near the flood-water surface. At lower temperatures, gas density increases, preventing the movement of CH₄ into the atmosphere. During this period, due to lower temperatures in the soil-water-atmosphere system, CH₄ emissions were lower than during the day.

The sigmoid curve enables us to infer that the results of the main data collection could be taken as the mean of a 24-hour period. This is corroborated by the results of the main collection, carried out in the morning of DAF 24, when the readings were 14.2 mg CH₄ m⁻² h⁻¹ in the chamber and 1.5 ppm of atmospheric CH₄, while the average values of the 24-hour collection were 16.3 mg CH₄ m⁻² h⁻¹ and 1.6 ppm, respectively. During the evaluation period, there was an increase of 1.4 mg CH₄ m⁻² h⁻¹ in the chamber for every one-degree increase in the flood-water temperature ($y=1.4x - 18.4$, $r^2 = 0.77$, $P < 0.01$).

In the 2nd collection, the data adjustment also produced a sigmoid curve (Figure 4). And an inverse relationship was also found between the minimum and maximum readings in both evaluations. Consequently, the considerations about the 1st data collection are equally valid for the 2nd data collection. The results obtained were 4.3 mg CH₄ m⁻² h⁻¹ in the chamber and 1.6 ppm of atmospheric CH₄, while the average values for the 24-hour collection were 3.9 mg CH₄ m⁻² h⁻¹ and 1.5 ppm, respectively. CH₄ emissions in the chamber increased with soil temperatures at 0.05 m (x_1) and flood-water temperatures (x_2), according to the formula $y=0.52x_1 + 0.13x_2 -10.3$ ($r^2 = 0.70$, $P < 0.05$).

In the 3rd collection, data adjustment again produced a sigmoid curve (Figure 5), and an inverse minimum-to-maximum relationship was also found for both evaluations (atmospheric CH₄ and chamber CH₄). Consequently, the considerations made for the previous data collections are also true for the 3rd collection. The results were 5.6 mg CH₄ m⁻² h⁻¹ in the chamber and 1.3 ppm of atmospheric CH₄, while the average values for the 24-hour collection were 7.2 mg CH₄ m⁻² h⁻¹ and 1.2 ppm, respectively. During the evaluation period, there was a 3.7 mg CH₄ m⁻² h⁻¹ increase in the chamber for every one-degree increase in flood-water temperature ($y=3.7x - 75$, $r^2 = 0.74$, $P < 0.01$).

The maximum variation in CH₄ emissions measured in the systems was 2.1 mg CH₄ m⁻² h⁻¹ in the NT system (2nd collection) and 11.2 mg CH₄ m⁻² h⁻¹ in the CT system (3rd collection). These evaluations were close to one another in time (12 days), with similar air, flood-water and soil temperatures (Table 1). Consequently, from the standpoint of the CH₄ emission pattern, on the basis of the intrinsic characteristics of each management system, the results show that the no tillage (NT) system can be more stable than the conventional tillage (CT) system.

4.0. REFERENCES

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5.0. FIGURES

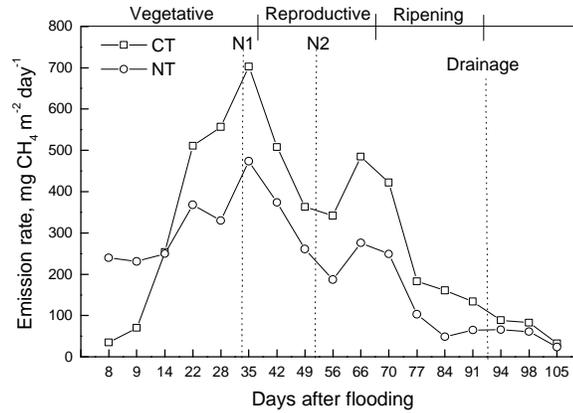


Figure 1. CH₄ emission rate in conventional tillage (CT) and no tillage (NT) in 98 days. Values are the average of two repeated measurements. N1 and N2 are N applications and drainage is the removal of flood water. Rio Grande do Sul, Brazil.

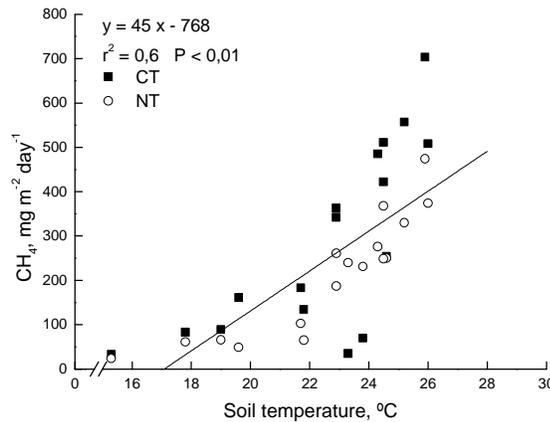


Figure 2. Relationship of CH₄ emission to average soil temperature in conventional tillage (CT) and no tillage (NT) during irrigated rice cultivation. Values are the average of two repeated measurements. Rio Grande do Sul, Brazil.

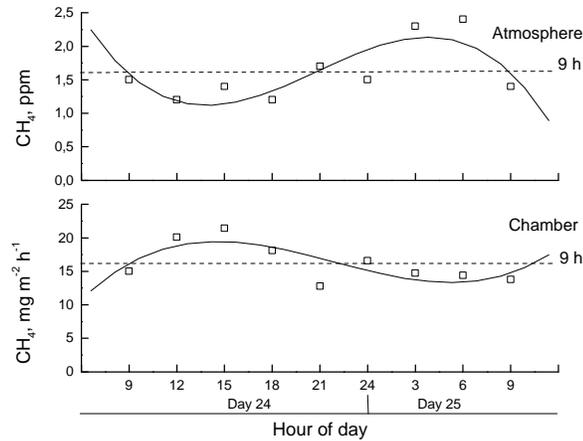


Figure 3. CH₄ emissions at different times of day in the CT plot, in the sample collection chamber and in the atmosphere (2 m height). February 24 and 25, 2003. The hatched lines represent the period means. Rio Grande do Sul, Brazil.

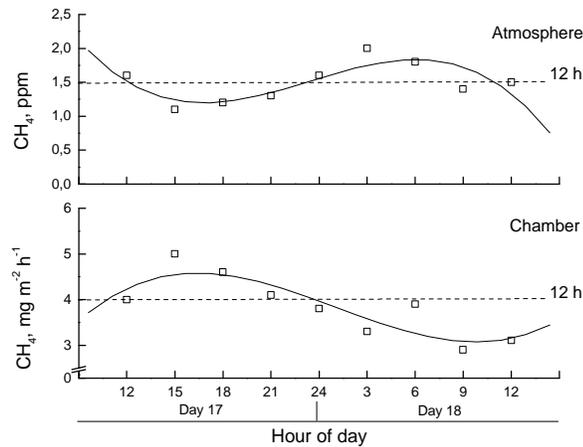


Figure 4. CH₄ emissions at different times of day in the NT plot, in the sample collection chamber and in the atmosphere (2 m height). March 17 and 18, 2003. The hatched lines represent the period means. Rio Grande do Sul, Brazil.

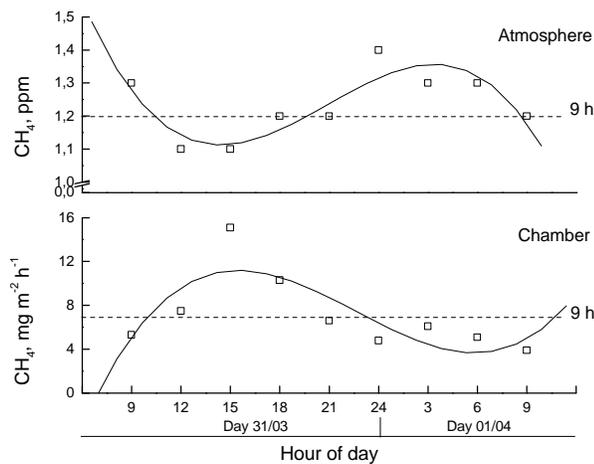


Figure 5. CH₄ emissions at different time of day in the CT plot, in the sample collection chamber and in atmosphere (2 m height). March 31st and April 1st, 2003. The hatched lines are the period means. Rio Grande do Sul, Brazil.