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CROP PRODUCTION

Methane emission from a flooded rice field under pre-germinated system

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ABSTRACT: *Local greenhouse gas flow measurement studies have been encouraged at a global level as a subsidy for national and state inventories. This study aimed to evaluate the seasonal methane emission during the 2008/2009 harvest, from an irrigated rice plantation, under pre-germinated system, in the municipality of Tremembé, State of São Paulo, using the static chamber technique and gas chromatography. The study showed high seasonal emission of methane (CH_4) for the studied area, probably due to the long flooding period. It was estimated the CH4 emission factor (6.51 kg CH_4 ha^{-1} dia^{-1}), the partial global warming potential (pGWP, 27.2 Mg CO_2eq growing $season^{-1}$ ha^{-1}) and the yield-scaled pGWP (YpGWP, 3.9 kg CO_2eq kg^{-1} grain).*

Key words: *flooded rice, pre-germinated system, methane.*

Emissão de metano em área de arroz irrigado sob sistema pré-germinado

RESUMO: *Estudos locais de mensuração de fluxos de gases de efeito estufa em sistemas agrícolas têm sido incentivados a nível global como base para subsidiar estimativas nacionais e estaduais de emissão. Este estudo objetivou quantificar a emissão sazonal de metano (CH_4) em cultivo de arroz irrigado, sob sistema pré-germinado, no município de Tremembé, Estado de São Paulo, na safra de 2008/2009, utilizando o método de câmara estática e cromatografia gasosa. O estudo mostrou elevada emissão sazonal de CH_4 para a área estudada, em função, provavelmente do longo período de inundação. Foi estimado o fator de emissão de CH_4 (6,51 kg CH_4 ha^{-1} dia^{-1}), o potencial de aquecimento global parcial (PAGp, 27,2 Mg CO_2eq estação de $crescimento^{-1}$ ha^{-1}) e o PAGp escalonado pelo rendimento (R) de grãos (PAGpR, 3,9 kg CO_2eq kg^{-1} grão).*

Palavras-chave: *arroz irrigado por inundação, sistema pré-germinado, metano.*

Cultivation of flooded rice produces methane (CH_4), a potent greenhouse gas. In Brazil, CH_4 emission from rice cultivation was estimated to be 0.46 Tg CH_4 in 2010 of a total of 12.42 Tg from the agricultural sector (BRAZIL, 2016). Local CH_4 measurement studies in flooded rice plantations have been carried out in different climatic regions, soils, and water and crop managements in the country (SILVA et al., 2011; ZSCHORNACK et al., 2011; MOTERLE et al., 2013; BAYER et al., 2014; LIMA et al., 2014; BAYER et al., 2015; ZSCHORNACK et al., 2016). However, few studies have been reported on rice production under pre-germinated system (LIMA et al., 2007; EBERHARDT et al., 2009), which is used in some regions of the country. The availability of data on CH_4 emission factors is a key element in conducting national and regional greenhouse gas emission inventories. Thus, in order to contribute with databases on CH_4 emission factors from flooded rice crop, the present study aimed to estimate the CH_4 emission factor from this cultivation under the pre-germinated system in a tropical area in the southeastern Brazil. It was also evaluated the partial GWP (*p*GWP) and the yield-scaled *p*GWP.

An on-farm experiment was carried out in the municipality of Tremembé, State of São Paulo, Brazil, situated at a latitude of 22º 56’ 12” S and longitude of 45º 34’ 07”W at a mean altitude of 580 meters. This municipality is one of the main rice producing areas of that state. The climate is of the Cwa type, characterized by an altitude tropical climate with rain in the summer and drought in the winter. Air temperature and rainfall during rice season were registered by an automatic meteorological station (Figure 1A). The soil is classified as Melanic Gleysoil (EMBRAPA, 2013), with the following physical and

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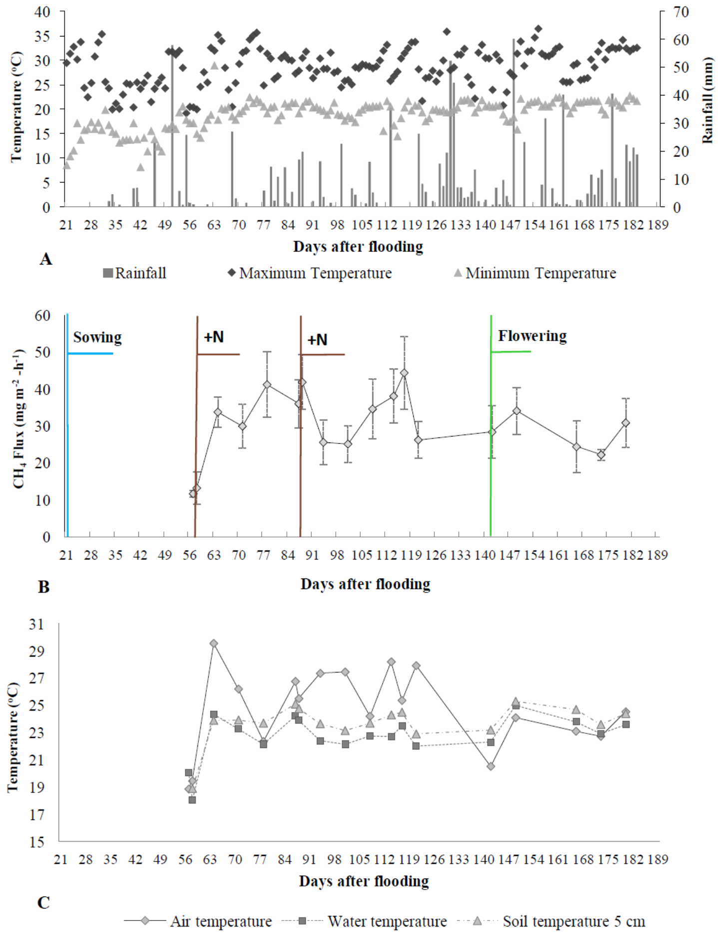

Figure 1 - (A) temperature (ºC) and rainfall (mm) registered at the meteorological station of Pindamonhangaba, SP, Brazil; (B) CH_4 flow (mg m^{-2} h^{-1}) in Tremembé, SP, Brazil; (C) temperatures (ºC) of the air, water and of the soil at 5 cm of depth; Continuous lines: blue = sowing; brown (+N) = application of nitrogen fertilizer (urea); green = flowering of the rice.

chemical characteristics at 0-20 cm depth: 41.4% sand, 36.0% silt and 22.6% clay; density: 1.31 g cm^{-3}; total porosity: 48.91 %; pH in H_2O= 5.55; total C=9.1 g kg^{-1}; total N=0.88 g kg^{-1}; P=3.63 mg dm^{-3}; K, Ca, Mg, H+Al=0.27, 1.09, 0.53, 3.35 $cmol_c$ dm^{-3}, respectively, and V=37.6% (Silva, 2009). Total C (TC) and total N (TN) contents were determined using an elementary C and N analyzer (Truspec-Leco). The experiment was carried out under broadcast pre-germinated system, during the 2008/2009 harvest, with continuous water irrigation, and consisted of a single treatment with three repetitions in a one hectare block. This type of cultivation is characterized by the use of pre-germinated seeds in previously flooded soil. Straw from the previous crop was incorporated into the soil after harvesting. The soil was plowed three months in advance and flooded twenty days before sowing, which occurred on 02/09/2008 with the emergency observed on 09/09/2008. This previous flooding was due to control of the red rice. The long-cycle variety SCS 114 Andosan (140 days) was used with a seed density of 140 kg per hectare. After flooding of the soil and the initial development of the seedlings, the height of the floodwater was maintained at an average of 16 cm. The agrochemical management was done according to regional technical recommendations.

At 49 days after flooding (DAF) were applied the herbicides Ricer (150 mL), Basagran (2 L) and Ally (10 g), and with the insecticide Curbix (200 mL) and Vegetoil (1 L). Covering fertilization was carried out twice, with the first at 58 DAF and the second at 85 DAF, using the formulation 25-0-25 (30 kg N ha^{-1} and 30 kg K_2O ha^{-1}). Urea and KCl were used as N and K sources. Flowering and complete ripening occurred, respectively, at 148 and 179 DAF. The static chamber method was used to collect the gas samples (IAEA, 1992). Gas sampling was conducted once a week on 18 occasions throughout the growing season (GS), beginning at 36 days after sowing (57 DAF) and ending at 176 DAF, before the harvest (10/02/2009), which was carried out with the soil still flooded. The gas samples were analyzed using an Agilent model GC6890 gas chromatograph, equipped with a 6-way valve, and a flame ionization detector (FID). Daily fluxes of CH_4 were calculated according to Bayer et al. (2014) and integrated to produce an estimate of the seasonal flow of CH_4, representing the accumulated emission for each chamber used. The estimation of the CH_4 seasonal emission considered the period from the sowing, although the soil was flooded twenty days earlier, until the complete ripening. The CH_4 emission factor was calculated from the division of the seasonal emission (ES) by the total of days of the GS, being expressed in kg CH_4 ha^{-1} d^{-1}. The partial global warming potential (*p*GWP), expressed in kg CO_2eq ha^{-1}, was calculated by multiplying the accumulated emission (seasonal) of CH_4 throughout the GS and its radioactive forcing potential ($pGWP_{CH4} = CH_4 * 28$), according to MYHRE et al. (2013). The yield-scaled global warming potential (Y*p*GWP) was also calculated as the ratio of the *p*GWP and the yield of rice grains (Bayer et al., 2014). While collecting the gases, the temperatures of the air, the floodwater and the soil at depth of 5 cm were registered using a five point Full Gauge thermometer. The air temperatures on the inside of each chamber were registered using digital thermometers (MULTI-Thermometer). The soil and water pH and oxidation-reduction potential (Eh) were measured using a Digimed digital pH-meter. Heights of the plants and of the floodwater were registered. The linear correlation coefficient between these variables and the CH_4 flow was determined using the procedure CORR of the SAS program (SAS, 2011). For a comparison of variability between the repetitions, the coefficient of variation (CV) was determined for cumulative CH_4 fluxes.

Increasing CH_4 flows were observed during the rice tillering period (Figure 1B). Increase in the number of tillers resulted in a greater CH_4 transport capacity as a function of the greater density and amount of aerenchyme (KIM et al., 2018). The variety SCS 114 Andosan is characterized by presenting high tillering, which could have contributed to the elevated CH_4 flows in this stage. Other emission peaks occurred near the panicle initiation stage (112 DAF) and flowering (148 DAF). GOGOI et al. (2005) also reported the occurrence of a high CH_4 flux at the panicle initiation stage, which was attributed to the decomposition of organic carbon in the form of root and leaf exudate and to the increased CH_4 transport capacity of the rice plant at this stage. The mean daily CH_4 emission was estimated as 616 mg of CH_4 m^{-2} d^{-1} (CV: 17.15%) and the accumulated emission during the season was 93.60 g CH_4 m^{-2} (CV: 17.15%), corresponding to a CH_4 emission factor of 6.51 kg CH_4 ha^{-1} d^{-1}, which is five times higher than the average indicated by the IPCC (2006), of 1.30 kg CH_4 ha^{-1} d^{-1}. The seasonal CH_4 emission evaluated in the present study is amongst the highest recorded in the measurement experiments conducted in the country. LIMA et al. (2007) also reported high seasonal CH_4 emission values in an experiment carried out in Itajaí, State of Santa Catarina, using the same cultivar (SCS 114 Andosan) under the pre-germinated system, with seasonal emissions accounting 68.84 g CH_4 m^{-2} (CV: 16.76%) and 138.21 g CH_4 m^{-2} (CV: 8.53%) for rice cultivation in mineral and organic soils, respectively. The high CH_4 emissions observed in the present study could be probably attributed to the long time under inundation in the pre-germinated system and to the long cycle of the variety, totaling 176 days of inundation from sowing to complete ripening. Impact of the continuous flooding on CH_4 emission is well known in the literature (IPCC, 2006; MOTERLE et al., 2013). Moreover, the rice variety used presents high CH_4 efflux potential, according to SILVA et al. (2014), although this effect was not evaluated in this study. The correlation analysis between the measured soil, water and meteorological variables and the CH_4 fluxes is presented in table 1. Positive and significant correlations were reported between CH_4 emission and air and water temperatures and soil temperature at 5 cm depth. Such relation has registered in numerous studies (WANG et al., 2017, FUMOTO et al., 2018). Data of these variables are presented in the Figure 1C. Plant and floodwater

Table 1 - Pearson's correlation coefficients and *P*-levels for the linear relationship between CH_4 emission and the variables measured.

	Tair	Twater	TS5	pHsoil	pHwater	Eh	Fw_height	Pl_height
CH_4	0.4536	0.6021	0.5731	-0.2696	-0.4295	-0.3288	-0.2607	0.1156
P	0.0374	0.0082	0.0162	0.2792	0.0753	0.1828	0.296	0.6480

Tair: air temperature registered at each sampling; Twater: water temperature; TS5: soil temperature at 5 cm of depth; Eh: oxy-reduction potential; Fw_height: floodwater depth; Pl_height: plant height.

height, soil and water pH, and oxide-reduction potential showed no significant correlations with CH_4 emissions. *p*GWP was evaluated as 27.2 Mg CO_2eq ha^{-1} GS^{-1}. Rice production was estimated as 6.8 t ha^{-1}, the value calculated for Y*p*GWP being 3.9 kg CO_2eq kg^{1} of grains, a value much higher than those reported in the literature (Table 2). This study resulted in a CH_4 emission factor (6.5 kg CH_4 ha^{-1} d^{-1}) for an irrigated rice production system typically used in the state of São Paulo, thus contributing to national

Table 2 - Seasonal *p*GWP emissions, expressed as CO_2eq ha^{-1} $season^{-1}$, grain yield in Mg ha^{-1}, and seasonal yield-scaled *p*GWP in kg CO_2eq kg^{-1} grain, from flooded rice cultivation areas in the south and southeast of Brazil under different forms of management.

Source	Local	Management	Seasonal *p*GWP (Mg CO_2eq ha^{-1} $season^{-1}$)	Grain yield (Mg ha^{-1})	Yield-scaled *p*GWP (kg CO_2eq kg^{-1} grain)
BAYER et al. (2014)	Cachoeirinha, RS	Conventional tillage	13.3[1,3]	7.9[1,3]	1.8[1,3]
		No tillage	10.3	7.7	1.4
BAYER et al. (2015)	Cachoeirinha, RS	Fall tillage	8.6[2,3]	8.1[2,3]	1.1[2,3]
		Spring tillage	10.9[2,3]	7.7[2,3]	1.4 [2,3]
ZSCHORNACK et al. (2016)	Cachoeirinha, RS	CF	10.7[4]	12.0[4]	0.9[4]
		II	6.8[4]	11.8[4]	0.6[4]
		CF	7.6[5]	10.7[5]	0.7[5]
		SII	2.0[5]	10.4[5]	0.2[5]
		FII	2.6[5]	10.9[5]	0.2[5]
MOTERLE et al. (2013)	Santa Maria, RS	CWR	12.8	9.3	1.4
		IWR	9.6	9.2	1.0
		CWR	13.3	7.1	1.9
		IWR	13.2	6.8	2.0
LIMA et al. (2007)	Itajaí, SC	PG - Mineral soil	19.3	9.9	1.9
		PG - Organic soil	38.7	4.8[6]	8.0[6]
EBERHARDT et al. (2009)	Itajaí, SC	PG - Mineral soil	15.6	9.1	1.7
		PG - Organic soil	17.2	6.7	2.6
		PG - Mineral soil	17.1	8.7	2.0
		Direct seeding in dry soil	11.5	8.7	1.3
Current study	Tremembé, SP	PG	27.2	6.8	3.9
LIMA et al. (2014)	Pindamonhangaba, SP	Transplanting	5.2[7]	5.7[7]	0.9[7]
Not published data	Pindamonhangaba, SP	PG	8.3	7.3	1.1

[1]Average of five agricultural years; [2]Average of seven agricultural years; [3]N_2O emissions included; [4]2009/10 agricultural year; [5]2010/11 agricultural year; [6]The low rice production was due to the occurrence of diseases; [7]Average of four agricultural years; CF: Continuous flooding; II: Intermittent irrigation; SII: Sparse intermittent irrigation; FII: Frequent intermittent irrigation; CWR: Continuous water regime; IWR: Intermittent water regime; PG: Pre-germinated.

and regional databases on CH_4 emission factors, which are critical for improving greenhouse gas emission estimates. Result also suggested that further studies should be conducted to investigate the impacts of the pre-germinated system on CH_4 emissions under different environmental conditions and varieties, as well as to identify emission mitigation options.

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DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

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