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Estimates of Seasonal Methane Emissions from Paddy-Rice Cropped at Pindamonhangaba Municipality, Brazil, Using DnDc Model

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Abstract: Agricultural activities have been pointed out as one of anthropogenic sources of greenhouse gas emissions, which influence on climatic changes. Information available at Intergovernmental Panel on Climatic Changes (Ipcc) indicated that methane emissions (CH₄) generated during the paddy-rice culture development phases is one of these activities and must be better investigated at field conditions. Computer tools that allow following the space-time dynamic of methane emissions from paddy-rice culture, considering the management involved, should also contribute to identify alternatives in order to minimize the high emission rates. Thereby, the Denitrification-Decomposition model (DnDc) can be used to investigate alternative scenarios in order to understand the paddy-rice methane emission process and to identify the critical points. However, DnDc validation is necessary to assure the reliability of those scenarios. Paddy-rice data collected during the seasons of 2004/2005 and 2005/2006 at Pindamonhangaba municipality, São Paulo State – Brazil, from Agrogases and Carboagro Projects, made possible to compare the quantified seasonal methane emissions from field with those estimated by the DnDc (version 8.9) scenarios. The DnDc/quantified seasonal methane emission rates reached were 0.99 for 2004/2005 and 0.70 for 2005/2006. On average, DnDc estimated the methane emissions $84.6 \pm 14.6\%$ close to those quantified from field.

Keywords: greenhouse gases; paddy-rice; validation; simulation; Brazil.

1. INTRODUCTION

The enhanced greenhouse gas emissions have been associated with anthropogenic sources, such as fossil fuels (oil, coal and natural gas) used on vehicles, industry, thermoelectric plants, landfill sites, deforestation, as well as in agricultural activities (agricultural waste burning, paddy-rice culture, livestock, agricultural soils), among others. They have been causing great global concern about the planet's future security due to the Earth's surface gradual heating levels rising (Ipcc, 2001).

For the matter, Embrapa Environment has been working on the last decades subsidizing the Brazilian agricultural greenhouse gas inventories, providing the agricultural reference reports and obtaining scientific knowledge about the factors involved with the national emission flows in order to elaborate more reliable estimates (Lima et al, 2006; Lima et al, 2003; Lima et al, 2001; Lima et al, 1999). This scientific knowledge is necessary to obtain more confident estimates for Brazilian country and for proceeding analysis about the factors involved with the management practices of agriculture that influence on their emissions. Therefore, will be both valuable to understand the greenhouse gas emission process on tropical climates in order to the future strategies proposals, which would be effectively useful to minimize the greenhouse gas emissions.

The paddy-rice culture is one of the important agricultural activities that promotes the greenhouse gas generation, specially methane (CH₄). Environmental characteristics of where the production system occurs can substantially interfere in the processes of nitrification, fermentation and denitrification, which also influence on the methane flows emitted. Thereby, the methane generation process in paddy soils needs to be well investigated. The process is driven by the CO₂ with H₂ reduction, with fatty acids or alcohols as hydrogen donors, and the acetic acid or methanol's transmethylation by the bacteria that produces methane. It is also important to consider that part of the methane produced in the soil is consumed on the oxidized rhizosphere of the rice's root or on the interface between the oxidized soil and the flooded water. Therefore, the methanotrophic bacteria population into the soil can increase due to their ability to metabolize CH₄ as their only source of carbon energy, despite the fact that other soil bacterias, such as the *Nitrosomonas* species, as example, would be also capable to consume methane. Herefore, it is also important to consider the carbon substrates and the soil nutrients availability in the paddy fields, which would be also promoted by the rice straw incorporation practices or using nitrogen fertilizers, due to their potential to increase significantly the methane emission rates.

The soil's composition and texture drastically affect the kinetic of the paddy-rice reduction process, despite the fact that the period between the soil flooding and the beginning of the methanogenesis be apparently different when considered the type of soil (Conrad, 1989). The redox potential influences the methane production in paddy-rice fields, since occurs the gradual reduction of the electrons in the soil after flooding and the fact that methane formation begins when Eh reaches values below -150mV (Patrick, 1981). It is also important to consider that the flooding increases the pH in acid soil, while it decreases in alkaline soil, due to Fe³⁺ to Fe²⁺ which, simultaneously, reduces the Eh. Therefore, the methane formation is efficient when pH ranging near to neutrality (6.4 to 7.8). Soil temperature needs also to be considered in the methane emission process, because affects the microorganism activities in the soil (Yamano & Sato, 1961).

It is relevant to consider that methane can also be leaching to underground water, as a small amount dissolved in water. Thereby, the decrease of methane rates in soil does not necessarily mean that all its methane has been sent to the atmosphere.

Equally important is to consider the existence of other factors, like local temperature, pluviosity and solar radiation, as well as, management practices, among those already mention, which somehow interferes in the methane gas liberation during the growing season.

Thereby, taking into account the necessity to consider a great number of complex factors involved with the methane emission process dynamic, which sometimes are also interacting each other, have been difficult to follow the space-time dynamic of methane emissions during the paddy-rice crop seasons, considering their different management involved with, in order to indentify alternatives which contributes to minimize the current emission rates. (Babu et al., 2005). So that, it is necessary to consider the use of available tools which promotes a systemic overview of how methane emissions depend on climatic factors, crop varieties used, soil type, applied fertilizers, water management, as well as other aspects involved with the local paddy rice culture management (Ipcc, 2001). Among the simulators available to make possible estimates of greenhouse gas emissions, it could be mention the following: NLOSS (Riley & Matson, 1989), DnDc (Li et al., 1992; Li, 2000), CASA (Potter et al, 1993), EXPERT_N (Baldioli et al., 1994), MEM (Cao et al., 1995), CENTURY (Parton et al., 1996) and DAYCENT (Del Grosso et al., 2002).

The “*Denitrification-Decomposition*” - DnDc (UNIVERSITY OF NEW HAMPSHIRE.ISEOS, 2006) is a process-oriented simulator formulated based on mathematic models, which describe the main processes involved on the representation of the nitrogen's and carbon's dynamics on soil and also the cultures growing, among others. By this way, DnDc estimate the carbon sequester and the emission of the NO, N₂O, CH₄ e NH₃ gases, as well as, to the agriculture ecosystems (Li, 2007; Li et al., 1994; Li et al. ;1992). Thereby, their results help the understanding the effects of the anthropic activities on the greenhouse gas emissions, as well as, their influences on the atmosphere balance of trace gas. The simulator considers detailed aspects of the productive system management, such as the existence of rotation, soil management, use of fertilizers and natural manure, water management, weed control, among others, which are integrated to the biogeochemical processes of nitrification, denitrification, culture's growth, water infiltration in soil, litter production, among others, in order to estimate the greenhouse gas rates (Li, 2000; Babu et al., 2005). Therefore, DnDc considers ecological variables that control the environmental factors of interest focused on their development, such as: a) local abiotic factors (maximum and minimum temperatures, pluviosity and solar radiation); b) physical and chemical aspects linked to the soil type considering its different horizon profile (bulk density, field capacity, wilting point, saturation, pH, among others); c) varieties characteristics; d) anthropogenic activities (culture management, soil, water, fertilizers, among others). These variables influence on environmental factors considered, which interferes on the soil's climate (temperature and humidity), and on its decomposition capability. DnDc also take into account the effects from evapotranspiration, evaporation, transpiration, water flow, redox potential (Eh) and oxygen consuming, on the N demand, as well as on the water absorption by the plant's root, daily biomass, daily water demand, influence of humates and resistant microbial compartments, among others. Thereby, the simulator incorporates the soil climate, culture growth, decomposition, nitrification, denitrification and, specially, fermentation submodels. More detailed information about variables and process considered by DnDc to evaluate methane (CH₄) emission by paddy-rice was mention by Li (2000), who also report that DnDc considers the flow of the CH₄ transported by rice plants by the gas concentration and the presence of aerenchyma, during the culture development. Li (2000) also presented that when there is no vegetated soil or plant with well-developed aerenchyma, DnDc considers the ebullition factor as a source of methane emission, which is evaluated when occurs only at the soil layer surface. So, the ebullition rate is measured by DnDc for its CH₄ concentration on the soil, temperature, porosity and aerenchyma's presence on the plant.

The potential use of DnDc to greenhouse gas estimates from different agricultural crops and practices have been reported by different countries like New Zealand, Australia, India, Canada, China, United States and Japan (Saggar et al., 2007; Beheydt et al., 2007; Babu et al., 2006, 2005; Miehle et al., 2006; Kiese et al., 2005; Li 2005; Shirato, 2005; Li & Saggar, 2004; Grant et al., 2004; Zhuang et al., 2004; Smith et al., 2002; Li et al., 1996). DnDc applications to estimate methane emissions from paddy-rice were presented by Babu et al. (2006, 2005), who presented applications for China, and Li et al (2004), who mentioned considerations for Eastern Asia.

In Brazil, Embrapa Environment, through the projects Agrogases and Carboagro, has been studding the DnDc applications for paddy-rice management system at Pindamonhangaba municipality, São Paulo State, and Itajaí Municipality, Santa Catarina State, considered two important rice producers for the country. The studied area located at Pindamonhangaba municipality has been followed since 2002/2003 season, when DnDc was first studied for calibration. This paper presents DnDc (version 8.9) validation considering paddy-rice crop data collected by Agrogases and Carboagro Projects during the 2004/2005 (year 2005) and 2005/2006 (year 2006) seasons at Pindamonhangaba municipality, São Paulo State – Brazil.

2. MATERIAL AND METHODS

2.1. Studied area

Information were provided from experiments conducted by Agrogases and Carboagro Projects at experimental areas located at the Paraíba Valley Regional Polo of Agribusiness Technological Development (APTA/PRDTA Vale do Paraíba), Pindamonhangaba municipality, São Paulo State – Brazil, at the central region of the Paraíba Valley (Figure 1) during the paddy-rice seasons of 2002/2003, 2004/2005 and 2005/2006. The area is located at the geographic coordinates of 22° 55' South Latitude and 45° 30' West Longitude and 560 meters of average altitude.

The climate is subtropical warm, dry winter and low rainfall rates, with a mean annual precipitation of 1000 mm (with rainfall well distributed through the year). The mean annual temperatures ranging from 17°C to 20°C, with an annual average of relative humidity of 74.9%. Agricultural activities predominant in Pindamonhangaba are rice, leaf greens, coffee, and sugarcane, among others.



Figure 1. Paraíba Valley localization

Soil type was classified as a GLEYSOL, in accordance with Fao Soil Unit classification. For over four decades, the land was used for paddy-rice culture. The paddy-rice variety considered was the IAC-103, whose main characteristics were reported by Bastos et al (2004), while the paddy-rice planting system was considered as the transplanting with planting in line.

2.2. DnDc simulation

Denitrification-Decomposition simulator (DnDc) (UNIVERSITY OF NEW HAMPSHIRE.ISEOS, 2006), 8.9 version, was used.

DnDc requires information to represent daily abiotic local factors (maximum and minimum temperatures, rainfall, solar radiation), crop management, water management, as well as, agrochemical applications (fertilizers and pesticide applications) and physical and chemical characteristics of the soil. Daily weather data were provided by APTA/PRDTA Vale do Paraíba.

Therefore, first of all it was considered the information for the 2002/2003 paddy-rice crop season on the studied area, which was provided by Agrogases Project, in order to evaluate the initial performance of DnDc, as well as, to develop its calibration. Afterward, it was considered as input data the crop management information gathered on the same studied area at 2004/2005 and 2005/2006 paddy-rice crop seasons, which were considered for DnDc validation. The information for the last two seasons were provided by Agrogases and Carboagro Projects. The simulated scenarios were evaluated separately by season. A greater soil bulk density was noticed for the season considered for DnDc calibration (2002/2003). The main aspects involved with them are showed on **Table 1**.

The methane emission reached on each simulated scenario were afterward compared with the respective seasonal methane emissions quantified in field monitoring (**Table 1**), which took into account the gases collected by syringes on field monitoring which were afterward evaluated at chemistry laboratory of Embrapa Environment.

Table1. Paddy-rice management considered for the evaluated scenarios

Crop seasons	Transplanting date (T) and Harvest date(H)	Fertilizer (Urea)	Flooding period
2002/2003 calibration	06/01/2003 (T)	30/01 (42 kg)	07/01 to 04/04
	07/05/2003 (H)	14/02 (42 kg)	
		28/02 (45 kg)	
		Total: 129 kg	Total: 88 days
2004/2005 validation	21/12(T)	10/01 (33 kg)	22/12 a 20/04
	09/05 (H)	15/02 (33 kg)	
		Total: 66 kg	Total: 119 days
2005/2006 validation	01/01(T)	27/01 (40 kg)	02/01 a 11/04
	23/05 (H)	14/02 (40 kg)	
		08/03 (40 kg)	
		Total: 120 kg	Total: 100 days

Obs: Information sources: Agrogases and Carboagro Projects;

Table2. Weather characteristics during the evaluated seasons considering the flooding period

Crop seasons	mean Tmax	mean Tmin	mean URmax	∑ Radiation	∑ Precipitation
	(°C)	(°C)	(%)	(MJ/m2/day)	(mm)
2002/2003 calibration	30.6 ± 3.3	19.7 ± 1.3	95.9 ± 2.7	556.2	471.9
2004/2005 validation	29.6 ± 2.9	20.2 ± 2.0	96.3 ± 3.0	823.9	475.8
2005/2006 validation	30.1 ± 2.7	20.6 ± 1.4	98.9 ± 1.0	476.8	591.9

Obs: Information Sources: Agrogases and Carboagro Projects;

3. RESULTS

The results are presented on **Table 3**. DnDc showed the best methane emission estimate for 2004/2005 season, where it was also noticed the greater radiation accumulated (823.9 MJ/m2/day) during the flooding period, when compared to the others. A minor difference between the maximum and minimum average temperatures was noticed, as well as, the highest water uptake (290mm). The minor grains (kg C/ha) produced during this season could be explained by the less N uptake (97 kg N/ha) occurred, when compared with the N demand expected (129 kg N/ha).

The worst methane emission estimate was reached for 2005/2006 season, where the precipitation accumulated was the highest (591.9 mm) and the accumulated radiation (476.8 MJ/m2/day) the smallest, when compared to the others.

The soil bulk density showed to be as the most important parameter on the estimates provided by DnDc, as observed during the calibration season (2002/2003). In this specific season it was found the greatest value of methane emission, 32,836.74 mgCH4/m2,

which was also determined by field monitoring, 27,956.52 mgCH₄/m². The soil bulk density (g/cm³) was 1.4 g/cm³, while the informed for the other seasons evaluated were 1.2 g/cm³. Thereby, in spite of the fact of the flooding period was the smallest (88 days) for 2002/2003 season, the soil bulk density drastically affected their emission process. This observation corroborating with the claim that soil's composition and texture drastically affect the kinetic of the paddy-rice reduction process, despite the fact that the period between the soil flooding. This factor's influence on the results must be more investigated on field situations, aiming for DnDc validation proposals to other locations in Brazil.

Table3. DnDc results provided by the evaluated scenarios and methane quantified from field.

Crop	water uptake (mm)	grains (kgC/ha)	Total amount of Degree Days gathered (TDD)	Methane emission estimated by DnDc considering 23eqC (mgCH ₄ /m ²)	Methane emission quantified from field data (mgCH ₄ /m ²)	DnDc/quantified rate
2002/2003	261	1,839	2,212	27,956.52	32,836.74	0,85
calibration						
2004/2005	290	1,532	2,209	18,765.22	18,910.00	0,99
2005/2006	261	1,833	2,210	11,578.26	16,529.16	0,70

Obs. Needs expected to the cultivar variety: a) water demand = 264mm; b) max. quantity of grains = 2,080 kgC/ha; c) degree day accumulated = 2,200;

DnDc also provide a useful screen presenting the interaction between the main factors involved with the methane emissions process during the period simulated (**Figure 1**).



Figure 1. Example of result provided by DnDc simulation.

4. CONCLUSION

The present paper presented the first text of DnDc model for paddy-rice field located at Pindamonhangaba municipality, São Paulo State – Brazil. DnDc presented good performance regarding paddy-rice seasonal methane emission estimates, where tropical characteristics are present. The simulator allowed to estimate methane emissions on average of $84.6 \pm 14.6\%$ close to those quantified from field, regarding only for seasons considered for validation. It was also noticed a DnDc/field quantified emission rate of 0.85 for the season regarded to calibration (2002/2003), which corroborate with the result reached for validation. The results indicated that DnDc is very sensible to soil bulk density parameter.

Take into account the results provided by this work, DnDc proved to be an important tool for estimating methane emissions from paddy-rice. Thereby, further tests in order to improve DnDc validation process considering others Brazilian paddy-rice regions are underway.

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