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Methane production and emission in surface and subsurface rice soils and their blends

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ABSTRACT

Methane (CH_4) production and emission from three rice-growing soils (Luisiana, Maahas and Pila) of Luzon Island in the Philippines were estimated by incubation and pot culture studies, respectively, to understand their interrelationship. Topsoil (0–20 cm depth) and subsoil (30–50 cm depth) were used for the study along with their blend (1:1) for generating a gradient in soil properties, which allowed evaluating the importance of organic carbon content in regulating CH_4 production in both layers of soil. For all the three soil samples, total CH_4 production showed a decreasing trend in the order Topsoil > 1Topsoil:1Subsoil > Subsoil. Inoculation by non-sterilized soil suspension in sterilized soils triggered higher CH_4 production. It was observed that with the addition of external organic substrates like rice straw, even subsoil produced appreciable amount of CH_4. Methane emission was also studied from the same soils cultivated with a rice seedling (IR-72) grown in pots. Temporal pattern of CH_4 emission deviated from temporal pattern of its production, i.e. emission patterns either showed a certain time lag (Luisiana and Pila soil) or no significant correlation to the CH_4 production (Maahas soil). Methane production and emission rates recorded in this study yielded significant relationship.

1. Introduction

Over the last 200 years, average global atmospheric methane (CH_4) concentrations have increased from about 730 ppbv to 1700 ppbv (Machida et al., 1994). However, the annual growth rates in its concentration showed considerable fluctuations in the past with a temporary cessation of growth around the turn of the millennium (Kai et al., 2011). Production as well as emission of CH_4, about 23 times more radiatively active than CO_2, is an important feature in the carbon cycle in flooded rice soils (Ramanathan et al., 1985). The intensity of CH_4 release from rice fields to the atmosphere is a function of management, climate as well as edaphic factors (Denier van der Gon et al., 1992; Neue and Sass, 1994; Yao et al., 1999; Mitra et al., 1999). Wetlands, including rice paddies, contribute between 15 and 45% of global methane emissions (Prather et al., 1995).

Methane emission rates primarily vary with changing soil properties and also the amount of organic matter applied(Yagi and Minami, 1990). Significant influence of soil properties on CH_4 emissions from rice fields has been reported by many authors (Bachelet and Neue, 1993; Xionghui et al., 2012). Methane is known to be produced in the last step of anaerobic degradation chain of organic matter, acetate or CO_2/H_2 being the immediate precursors. Efficiency in converting acetate to methane differed among eleven Philippine rice soils, ranging between 16.5 and 66.7% of the added acetate, which was utilized within five weeks of incubation at 25 °C (Wassmann et al., 1998). Wachinger et al. (2000) investigated spatial heterogeneity of CH_4 production on 1 cm scale and the role of organic material on CH_4 production in undisturbed soil cores of two mineral and one peaty wetland soils, incubated for 3 months. Fresh organic material was observed in all highly productive soil cores, whereas soil cores with low methanogenic activity included far less fresh organic material. The observed hot spots of fresh organic material were correlated to high amounts of Archaea and the most dominant factor for the spatial variation in CH_4 production on the micro-scale was found to be the distribution of fresh organic material, which activated and possibly attracted methanogenic Archaea, i.e. methanogens. Root exudates as organic substrates also help enhance CH_4 production in root zone (Aulakh et al., 2001). Apart from carbon, CH_4 production is influenced by various soil parameters like presence of inorganic elements, methanogenic population, soil water, aeration, temperature, soil Eh, pH, and salts (Segers, 1998; Yao et al., 1999; Le Mer and Roger, 2001).

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Table 1
Geographical location and order of the soils used for the present study.

Soil location name	Province	Latitude	Longitude	Soil order
Pila	Laguna	14°26′24″N	121°27′01″E	Andaqueptic Haplaquoll
Luisiana	Laguna	14°10′15″N	121°30′25″E	Aquic Troporthent
Maahas	Laguna	14°09′53″N	120°15′14″E	Andaqueptic Haplaquoll

Ideally, the inherent potential of a soil to stimulate CH_4 production should be integrated into regional and/or global CH_4 databases that are used to estimate GHG emissions at regional or national scale. At present, however, the guidelines for computing emissions (IPCC, 2007) do not consider soil factors in the upscaling procedures. GHG estimates from rice agriculture could greatly be improved by linking potential CH_4 production of rice soils to a geo-referenced soil database (Denier van der Gon, 1996).

This study comprises of two experiments to characterize both CH_4 production and emission in soils collected from rice fields. Topsoil and subsoil samples were collected for each soil type to understand differential features that might control CH_4 production potential and emissions from these soils. A blend (1:1) of topsoil and subsoil was made which created a gradient in intrinsic soil organic carbon content to trace its specific impact on CH_4 production and emissions while other soil properties were found to remain largely unchanged in the blends. The impact of various imposed conditions (sterilization followed by inoculation, sonication) on the CH_4 production potentials of topsoils and subsoils and their blends were also tested. The tested hypothesis was: CH_4 production potential of a soil has a reasonable degree of interrelationship with the emission from the same under field condition so that emissions could be presumed from soils' production potentials. This work would help test the correlation between production and emission of CH_4 in topsoils and subsoils and their blends and in turn would be able to highlight the appropriateness of measuring CH_4 production potential of top and sub soils and roughly predicting their emission potentials. This would be especially beneficial in case of production or emission from subsoils, which is difficult to measure in a rice field. Also, since subsoil CH_4 may not always find its way to the atmosphere, it may be important to know the CH_4 production potentials of subsoil layers, as in long-term farming the subsoil may become exposed to the cultivation practices. Moreover, CH_4 production in subsoil is ecologically important for various microbial groups like methanotrophs for example and so could indicate the potential growth of these microbial groups in subsoil layers.

2. Materials and methods

2.1. Soil collection, preparation and analysis

Three soil types (Table 1), primarily used for rice cultivation, with a wide range of different soil properties (Table 2) had been selected from three different locations in Luzon Island in the Philippines to study CH_4 production potential and emissions from their surface and subsurface layers. The topsoil and subsoil layer samples were blended (1:1) for generating gradients in soil properties for each of the three soil types. Soil samples were collected at different spots over the rice field from two depths, i.e. 0–20 cm (topsoil) and 30–50 cm (subsoil) in 3 replicates, by a soil core sampler during dry fallow period. The 20–30 cm soil layer was discarded to avoid possible mixing of the top and sub soil. The entire volume of each soil layer (topsoil and subsoil) was mixed separately and thoroughly to generate a composite sample and a sub-sample was taken for physico-chemical analysis. After air-drying, the soil samples were ground and passed through 80 mesh sieve. The subsamples of air-dried topsoil and subsoil were now blended in 1:1 ratio and mixed thoroughly in a plastic container. The final soil samples (top, sub and 1:1 blend) were stored in darkness at 25 °C for 6 weeks until the incubation or pot experiment was undertaken. Although soil drying may reduce the activity of microbial cells but once they are exposed to favorable conditions of temperature and moisture they regain their activity (Martía et al., 2012). The soils were analyzed for total carbon, total N (CHN analyzer, Perkin Elmer), available P (Olsen et al., 1954), ammonium acetate exchangeable K (McKeague, 1978), active (dithionite extractable) Fe and Mn (Asami and Kumada, 1959), cation exchange capacity (Ministry of Agriculture and Food, 1981), pH (Peech, 1965) and texture (Piper, 1967). All analyses were done in 3 replicates.

2.2. Incubation experiment

2.2.1. Treatments

2.2.1.1. Sterilization. In this treatment, a set of beakers fitted with rubber cork, pH and Eh electrodes and filled with soil suspensions were sterilized at 121 °C for 40 min in an autoclave. After sterilization, the beakers were incubated in an incubator at 30 °C for 86 days. Non-sterilized soil counterparts were incubated as the controls. Few extra non-sterilized beakers were kept for withdrawing 2 drops, approximately measuring 0.1 ml of soil suspension for inoculating sterilized soils on the 16th DOI (days of incubation).

2.2.1.2. Sonication. Another set of beakers fitted with rubber cork, pH and Eh electrodes containing the soil suspension were sonicated in a sonicator-ultrasonic processor at 100 W for 5 min. The beakers were kept in a water bath during sonication to reduce heating of the samples. Sonication helps releasing some light organic carbon

Table 2
Physico-chemical properties of topsoil, subsoil and their blend (1:1).

Soils	Code	pH (1:1 H_2O)	Active Fe (%)	Available P (mg kg^{-1})	Available K (mequiv. 100 g^{-1} soil)	Total N (g kg^{-1})	Total C (g kg^{-1})	Clay (%)	Silt (%)	Sand (%)
Luisiana	Topsoil	4.30	4.33	4.1	0.14	1.84	18.13	29	66	5
	Topsoil:subsoil (1:1)	5.9	4.11	5.1	0.25	0.90	9.01	68	30	2
	Subsoil	5.3	4.31	3.1	0.28	0.58	0.57	51	43	6
Maahas	Topsoil	6.40	2.05	15.0	0.94	1.55	16.40	55	36	9
	Topsoil:subsoil (1:1)	7.2	2.97	13	0.73	0.70	7.52	52	44	4
	Subsoil	6.8	3.13	3.5	0.64	0.28	2.60	43	54	3
Pila	Topsoil	7.50	0.50	62.0	0.44	3.64	45.50	21	58	21
	Topsoil:subsoil (1:1)	7.9	0.94	67	0.42	3	26	35	54	11
	Subsoil	7.1	0.50	19	0.35	1.85	1.94	44	47	9