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Methane Emission from the Wetland Rice Fields in Sagar Island, Ne Coast of Bay of Bengal, India*

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Abstract: Average rate of CH_4 emission from the rice field mostly reclaimed from mangrove swamp in northwestern boundary of Sundarban (NE coast of Bay of Bengal, India) was found to be 0.98 µg m^{-2} s^{-1} with a maximum rate of 3.04 µg m^{-2} s^{-1} during waterlogged condition in September. Methane emission showed lower mean rate of 0.98 µg m^{-2} s^{-1} from the fertilized rice fields in the reclaimed area compared to that of virgin Indian mangrove forest (2.73 µg m^{-2} s^{-1}), Indian upland rice fields (4.3 µg m^{-2} s^{-1}) as well as South East Asian and temperate rice fields (3.0 µg m^{-2} s^{-1}). Inhibition of methanogenesis by sulphate reducer in the mangrove sediment as well as in the rice fields reclaimed from virgin mangrove forest could cause lower emission rate compared to the upland rice fields where sulphate reduction could be limited due to less abundance of sulphate. Further decrease of emission rate in the rice fields reclaimed from mangrove forest compared to that of the mangrove sediment suggested that ammonia based fertilizer stimulated methane oxidation. Expansion of harvested area for rice agriculture by reclaiming mangrove swamp needs efficient management to control further increase in atmospheric methane.

Key words: Methane emission, wetland rice fields, Sundarban

Introduction

The atmospheric concentration of methane has increased by 2.5 times since the pre-industrial era (IPCC, 2001), although during last two decades, the annual increase in atmospheric methane concentrations have slowed down to 1 to 0.5% (Dlugokencky *et al*., 2003). To mitigate future environmental impacts due to the increased methane concentrations in the atmosphere it is required updated knowledge of source strength in order to adopt proper strategies for the reduction of methane emission. Methane emission intensity shows considerable variation in space and time with respect to the numerous natural and anthropogenic sources (Bartlett and Harriss, 1993; Banker *et al*., 1995; Mukhopadhyay *et al*., 2002). Global budget estimates for methane have shown that wetlands are the largest biogenic source of atmospheric methane and rice fields account for 15-20% of the world's total anthropogenic methane emission (Khalil and Shearer, 1993; Neue, 1993). Tropical regions have several characteristic features different from the other areas of the world, such as thin ozone column and larger dosage of UV-B radiation along with high tropopause. This results in the occurrence of high concentration of OH radical, which leads to the atmospheric destruction of CH_4. The pronounced

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increase of methane oxidation rate is found to occur after rapid industrialization (Crutzen, 1995) in the tropical region. Methane molecules are destroyed not only by reacting with OH radicals in the atmosphere, but are also oxidized in soil. Oxidation by soils accounts for 5% of the global CH_4 sink (IPCC 1996). Mitic *et al*. 1995, studied the influence of spatial variability of physical surface characteristics on transport dynamics of CH_4 flux in relation to the coherent turbulent structure. As with methane production and methane emission rates are highly variable in the wetland rice fields (Lindau *et al*., 1991; Seilar *et al*., 1984). India is the second largest producer of rice in the world after China, though annual rate of production per hectare of land in India is far behind than those of China and Japan. However, in India, during the last few decades the per hectare production rate of rice was enhanced to about 2.6 times (IRRI, 1991). Because rice agriculture is one of the few sources of methane where emission reduction through management is considered possible, it is required better understanding how this source is changing with time due to expansion of harvested area and intensified fertilizer application. The world area under rice cultivation was only 104 million ha in 1951 and has increased to 148 million ha in 1993 (IRRI, 1995). Rice agriculture will expand by up to 70% over the next 25 years (Dubey, 2001). The Indian Sundarban mangrove forest (21°32′ and 22°40′ N, 88° 05′ and 89°E) comprises of 9630 sq km, out of which about 5366 sq km has been reclaimed for inhabitation and agricultural purposes. The influence of land use change through the conversion of wetland to the agricultural field on methane emission remains poorly studied. This seems to change the total emission budget of CH_4 from the paddy field in this region. North East coast of Bay of Bengal is highly irregular and crisscrossed by several rivers and waterways. Several discrete islands constitute this coast. Sagar Island situated at the confluence of Hooghly River and Bay of Bengal, (22°42.9′ N and 88°1.3′ E) and mostly reclaimed from mangrove swamp, has a triangular outline with a length of 30 km north-south and maximum width of 10 km east west towards south. On the east and west of this island are Baratala and Hooghly tidal rivers, respectively (Fig.1). This study is undertaken for systematic monitoring of direct CH_4 flux measurements from wetland rice fields, reclaimed from mangrove forest, over the entire growing season in the land ocean boundary condition of NE coast of Bay of Bengal, Sagar Island with a view to compare the results reported for the virgin wetlands and rice fields in the other parts of the world.

Materials and Methods

Sampling begun in April 2000 and continued until December 2000 covering southwest (June to September) and northeast (October to December) monsoon at two sites (St.1 and St.2) simultaneously used for rice cultivation at the center of the Island. Samples were also collected from Seamapore tower, Sagar Island (south) 250 m from the shoreline of beach site (Stn.3) (Fig. 1). Air samples in triplicate were collected at 1m and 10 m height with the help of a portable air sampler (APS 2, Lawarance and Mayo) at a rate of 2 $Lmin^{-1}$ and drawn into pre evacuated glass sampling bulbs (100 mL) for 15 min at 3 h intervals for 24 h at each site. Samplings were continued for three consecutive days from full moon in every 4 weeks between April and December 2000. Samples were transported to the laboratory for the determination of CH_4 by gas chromatography. A Shimadzu 14 B GC fitted with a stainless steel Porapak Q column (2 m x 0.32 cm) maintained at a temperature of 35°C and a flame ionization detector was used for the purpose. High purity nitrogen was used as the carrier gas. Standard methane (2.25 ppmv) procured from Chemtron Limited was used for calibration. Relative uncertainty for methane measurement was found to be 2.9%. Micrometeorological data (temperature, wind velocity, humidity and pressure) were also recorded simultaneously by using a computerized weather station (Model No. DAVIS 7440). Wetlands rice fields were prepared in April (soon after first

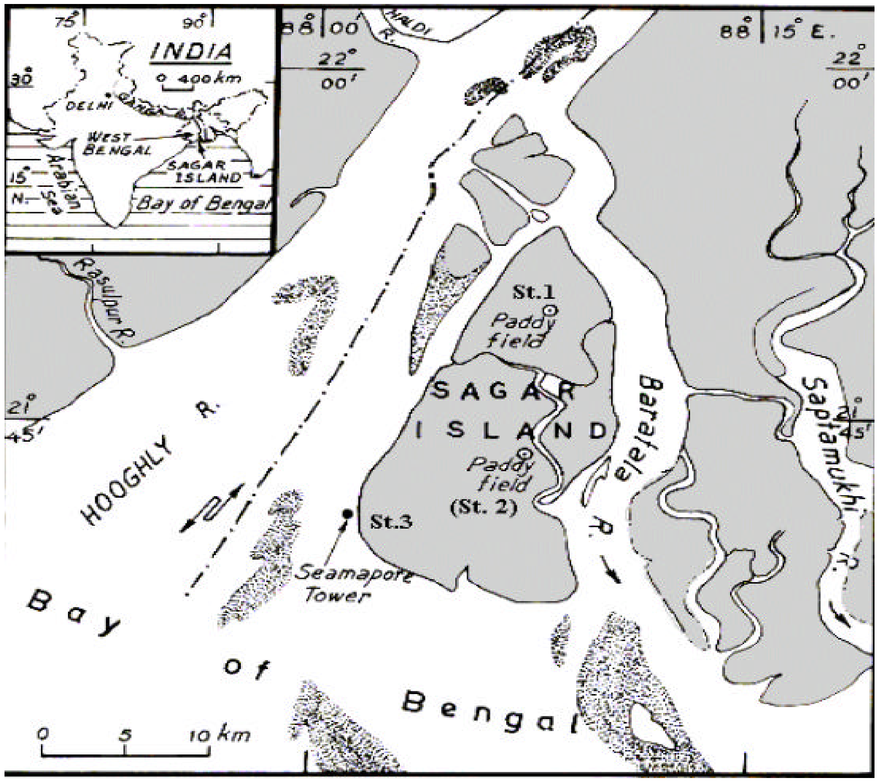

Fig. 1: Location map of the study area

shower after dry season) before transplantation and urea (60-70 kg /hector) was applied in two splits. First splits were applied shortly after planting and the remainder was broadcast at later growth stage, especially at the panicle initiation. Rice was planted covering almost entire Island soon after the onset of monsoon (June). Building dikes retained water and the rice fields remained water logged for almost six months. Wet tillage of common varieties of rice (IR-8, IR-22, Masuri, Dudheswar etc) in rows at 15 cm apart was the age-old cultural practice adopted by the local farmers. Grain yields were 12 to 6 t ha^{-1}.

Area Source Solution

Emission rates were calculated using a box model in which it was assumed that the CH_4 from all sources upwind is uniformly distributed up to height 'h'. When air flows from offshore to onshore, it was modified by changes in roughness, which produce a mechanical internal boundary layer and/or by temperature contrast, which produce a thermal or convective internal boundary layer (CIBL). This CIBL is considered as effective lid height and its height was calculated using the formula (Sethu Raman *et al*., 1980):

$$h = [\ 2C_D\ (\theta_{land} - \theta_{sea})\ x / \gamma(1-2F)\ ]^{1/2} \quad (1)$$

where, γ is the lapse rate upwind condition; F is an entrainment coefficient; θ_{land} and θ_{sea} are the potential air temperature over land and water, respectively and x is the distance of fetch down wind from the shore line. Using the value of drag coefficient, C_D and F (Driedonk, 1982) and transfer to the next phase considering the fetch distance x of 30 km equal to be the length of the Sagar Island from sea end, values of CIBL were found to lie between 113 and 409 m and $\chi_C(x)$ is the accumulated ground level concentration at a distance from the upwind edge over an area source with area average rate of emission per unit area, q, in which allowance has been made for progressive vertical spreading and is represented by Lucas (1967):

$$q = \frac{\chi_C(x)\,\bar{u}.\sigma_z(x)(1-s)}{(2/\pi)^{1/2}.\,x},\quad 0<s<1 \tag{2}$$

where, $\sigma_z(x) = a\,x^S$; $0.1 \leq x \leq 10$ km and $\bar{u}$, time average wind speed. Values of a and s are computed according to Pasquill and Smith (1983). Off shore wind concentration (back ground value), χ_a is modified during down wind traverse of distance x and over area source and sink to $\chi_a \pm \chi_C(x)$. Considering seasonal variation in stability categories in terms of wind speed, insolation and state of sky appropriate values of a and s were used to calculate q. Air dried soil samples of 30 gm collected from surface (0-10 cm) of the mud flats in the virgin mangrove forest and paddy field was extracted in 75 ml of 2 mol L^{-1} NaCl and NH_4-N and NO_3-N were analyzed using spectrophotometric method and SO_4^{-2} by turbidimetric method in the extract (APHA, 1995). An additional 30 gm sub-sample was weighed into 100 ml beaker, covered and incubated for 30 days in the dark closed chamber. At the end of the 30 days incubation, samples were again extracted with NaCl (2 mol L^{-1}) solution and NO_3-N and NH_4-N were determined as described above. Organic carbon was analyzed by chromic acid method (Walkley and Black, 1934). Net nitrification was calculated as the change in NO_3-N concentration per gram of dry mass soil divided by the time period of aerobic incubation (Riley and Vitousek, 1995). Air-dried samples were used for the grain size analysis following pipette method (Piper, 1950).

Results and Discussion

Monthly variations of mixing ratio of methane in the atmosphere over paddy fields and beach site were studied. Little variation of mixing ratio of methane at the offshore station was observed during the study period in contrast to the paddy field (Table 1). Its value was considerably increased in September over the paddy field. However, the lateral transport of methane from the paddy field could increase its concentration in the off shore atmosphere. The difference of mixing ratios of CH_4 over the paddy field and offshore station (Fig. 2) was considered. Using the modified concentration during downwind traverse of a distance of 30 km and employing Eq. 2, the box model values of uniform rate of exchange of CH_4, (q), were calculated. Variation of 'q' was found between 0.05 and 3.04 $\mu g\ m^{-2}\ s^{-1}$ with an average of 0.98 $\mu g\ m^{-2}\ s^{-1}$ (Table 3). The patterns generally showed increasing emission rates as the growing season progressed. Bandopadhyay *et al*. (1996) calculated mean methane flux from Indian upland paddy field to be 0.299 $\mu g\ m^{-2}\ s^{-1}$. A national methane measurement campaign in India yielded a range of methane flux values between-0,05-1 $\mu g\ m^{-2}\ s^{-1}$ for irrigated intermittently flooded rice fields, 0.01-18.3 $\mu g\ m^{-2}\ s^{-1}$ for flooded fields and between 0.3-6.5 $\mu g\ m^{-2}\ s^{-1}$ for deep-water regimes, with an average of 4.3 $\mu g\ m^{-2}\ s^{-1}$ (Dubey, 2001) Average emission rates during the growing season was found to be 16.7 $\mu g\ m^{-2}\ s^{-1}$ from rice fields at Tuzu in the Sczhuan Province of China

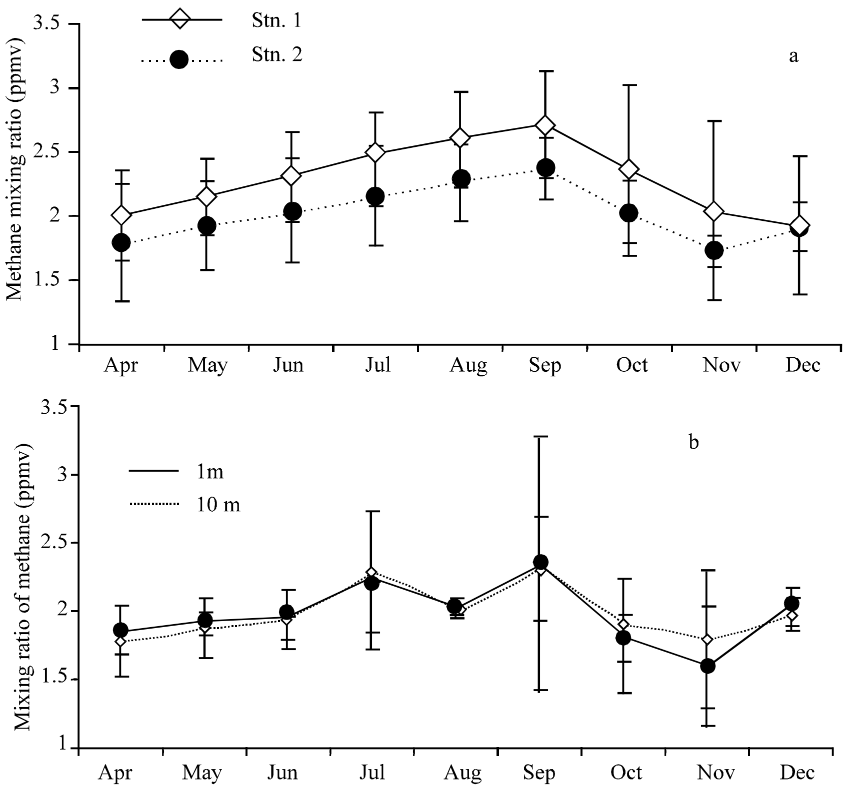

Fig. 2: Monthly variation of methane mixing ratio in the atmosphere a) Paddy field (Stns.1 and 2) b) Offshore station (Stn. 3).

(Khalil *et al*., 1991). The estimates of methane emission vary widely i.e., from 5.0-7.5 μg m^{-2} s^{-1} in Indonesia, 5.4-8.9 μg m^{-2} s^{-1} in Thailand and 5.3-21.9 μg m^{-2} s^{-1} in Philippines, with an average of 9.0 μg m^{-2} s^{-1} (Nugraho *et al*., 1994; Yagi *et al*., 1994; Neue, 1993). Methane emission is relatively lower from temperate rice fields in the United States (1.58-5.2 μg m^{-2} s^{-1}), Italy (1.85-5.06 μg m^{-2} s^{-1}) and Spain (1.1 μg m^{-2} s^{-1})(Cicerone and Oremland, 1988; Seiler *et al*., 1984; Schutz *et al*., 1989b; Yao *et al*., 1997), with an average of 3.0 μg m^{-2} s^{-1}. Methane emission (1.2-4.6 μg m^{-2} s^{-1}) was found by Fisher *et al*. (1990) to be strongly related to the above ground biomass (500-2250 g m^{-2}) in the Lake Charles field.

CH_4 fluxes from coastal saline marshes have been reported to be between 0.027 and 1.68 μg m^{-2} s^{-1} (Bartlett *et al*., 1987). Methane fluxes from mangrove swamps have been reported in Florida (Harriss *et al*., 1998; Barber *et al*., 1998) with low values of about 3.5 ng m^{-2} s^{-1} and in Puerto Rico (Sotomayor et al., 1994) with values of 3.5 ng m^{-2} s^{-1} for un-impacted and 0.05 to 0.95 μg m^{-2} s^{-1} for the impacted mangroves. In Australian mangrove ecosystem low methane emission rate (5.5-97.2 ng m^{-2} s^{-1}) was accounted for inhibition of methanogenesis at high salinity by sulphate reducing bacteria because of out-completion for substrates (Kreuzwieser *et al*., 2003). Mukhopadhyay *et al*. (2002) reported methane emission of 1.37 μg m^{-2} s^{-1} in the virgin mangrove forest of Sundarbans, NE Coast of Bay of Bengal and its value in the Coastal wetlands of South

Table 1: Values of methane and its flux along with meteorological parameters during SW and NE monsoon at paddy field (average of Stns 1 & 2) and offshore (average of St. 3)

	Paddy field		Off shore	
	SW monsoon	NE monsoon	SW monsoon	NE monsoon
Temperature (°C)	29.6	25.96	30.7	24.1
Wind velocity (m s^{-1})	1.22	0.58	4.89	2.2
Methane concentration (ppmv)	2.43	1.88	2.3	1.83
CIBL (m)	113	162	-	-
Methane flux (μg m^{-2} s^{-1})	1.60	0.77	-	-

Table 2: Substrate concentration and rate of nitrification (mean ± SD) in the sediment (0-10 cm) collected from virgin mangrove mudflats and paddy fields reclaimed from mangrove forest

	Mangrove mudflats	Paddy field
Sand (%)	6.33±1.43	17.0±5.3
Silt (%)	89.5±3.19	80.2±6.83
Clay (%)	4.66±1.27	2.84±1.55
Nitrate-N (μg g^{-1})	1.13±0.24	1.09±0.51
Ammonium-N (μg g^{-1})	3.31±2.81	7.93±7.6
Organic carbon (%)	0.47±0.27	0.92±0.15
Sulfate (mg g^{-1})	1.43±0.14	1.30±0.47
Rate of nitrification (μg g^{-1} d^{-1})	0.098±0.055	0.178±0.09

Table 3: Monthly variations of methane flux from paddy field (mean±SD)

Month	Methane flux (μg m^{-2} s^{-1})
April	0.13±0.52
May	0.16±0.43
June	1.10±0.41
July	1.21±0.47
Aug	0.89±0.45
Sep	3.04±0.48
Oct	1.94±0.69
Nov	0.05±0.68
Dec	0.31±0.55

India was found to be 0.83-6 μg m^{-2} s^{-1} (Purvaja and Ramesh, 2001). Higher CH_4 production in the mangrove sediment with high clay content (Table 2) could result by diffusion, proproot or pneumatophores-mediated transport and formation of more bubbles, which pass through the outgoing oxic sediment surface so rapidly that there was little chance for CH_4 to be deoxidized by methanotrophs. Different types of substrates such as organic matter, nitrate, sulfate etc. and high clay content may influence methane production (Neue, 1993; Giani *et al*., 1996). Electron acceptors such as nitrate or sulfate inhibit CH_4 production by competition. Any input of these substrate by the way of applying fertilizers or nitrification of ammonia to nitrate will affect CH_4 production (Schutz *et al*., 1989; Bodelier *et al*., 2000). Analytical results for the substrates occurring in the sediment of the paddy field and virgin mangrove mudflats are given in Table 2. Results showed the higher concentrations of organic carbon and ammonia with higher rates of nitrification in the paddy fields with low clay contents than those observed in the mangrove mudflats. Higher concentration of ammonia in the rice field was due to application of urea. Since all known methanogens use NH_4^+ as nitrogen source, ammonia-based fertilizer could have the stimulatory effect of on methane production (Palmer and Reeve, 1993). In spite of the increased rate of nitrification in the paddy field compared to that of mangrove sediment, occurrence of large concentration of ammonia was observed and it did not show stimulatory effect on methanogen for enhance methane production. Schutz *et al*. (1989a) observed decreased CH_4 emission from paddy field after application of urea. Bodelier *et al*. (2000) observed 57% decrease of methane emission after application of ammonia based fertilizer. Limited diffusion of methane could be due to its oxidation before it was reached the atmosphere (Sass *et al*., 1991). Rice plants supply atmospheric oxygen to the roots for respiration via the aerenchyma and the intercellular gas space system by diffusion (Teal and Kanwigher, 1966; Dacey, 1980). The aerenchyma has its own openings at the leaf sheath (Nouchi *et al*., 1991) and the gas supply to and from the roots constitutes an important part of the roots oxidizing power, aside from enzymatic hydrogen peroxide production. Methane-oxidizing bacteria could be abundant in the rhizosphere and rhizosphere's potential for methane oxidation was expected to be high (De Bont *et al*., 1978; Cicerone and Oremland, 1988). Ammonia oxyginase in nitrifiers could also provide an important pathway for the aerobic oxidation of methane in the rice field (Ward, 1987).

Methane emission showed lower mean rate of 0.98 $\mu g\ m^{-2}\ s^{-1}$ from the fertilized rice fields in the reclaimed area compared to that of virgin Indian mangrove forest (2.73 $\mu g\ m^{-2}\ s^{-1}$), Indian upland rice fields (4.3 $\mu g\ m^{-2}\ s^{-1}$) as well as South East Asian and temperate rice fields (3.0 $\mu g\ m^{-2}\ s^{-1}$).

Inhibition of methanogenesis by sulphate reducer in the mangrove sediment as well as rice fields reclaimed from virgin mangrove forest could cause lower emission rate compared to upland rice fields where sulphate reduction could be limited due to less abundance of sulphate (Verma *et al*., 2002; Kreuzwieser *et al*., 2003). Further decrease of emission rate in the rice fields reclaimed from mangrove forest compared to that from the mangrove sediment suggested that ammonia based fertilizer stimulated methane oxidation.

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