CMFRI

Winter School on

Impact of Climate Change on Indian Marine Fisheries

Lecture Notes

Part 1

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(18.01.2008 - 07.02.2008)

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METHANE EMISSION FROM RICE FIELD AND MITIGATION OPTIONS

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Introduction

Methane gas is a valuable energy resource and the leading anthropogenic contributor to global warming after carbon dioxide. Methane accounts for 17 percent of the enhanced greenhouse effect (IPCC, 1996). Over the last two centuries, methane's concentration in the atmosphere has more than doubled from about 700 parts per billion by volume (ppbv) in pre-industrial times to 1,730 ppbv in 1997 (IPCC, 1996). The global tropospheric CH_4 growth rate averaged over the period 1992 through 1998 is about 4.9 ppb per year, corresponding to an average annual increase in atmospheric burden of 14 Tg.

Sources of Methane Emissions

Methane is emitted into the atmosphere from both natural and anthropogenic sources. Natural sources include wetlands, tundra, bogs, swamps, termites, wildfires, methane hydrates, and oceans and freshwaters. Anthropogenic sources include landfills, natural gas and oil production and processing, coal mining, agriculture (livestock enteric fermentation and livestock manure management, and rice cultivation), and various other sources.

Rice field methane emission

To feed the increasing global human population, the world's annual rice production must increase from the present 528 million tonnes (m t) to 760 m t by the year 2020. According to a current estimate, rice agriculture will expand by up to 70% over the next 25 years. Recent studies indicated that the CH_4 release per m^2 and per year from different rice ecosystems follows the order: deep-water rice > irrigated rice > rainfed rice. Worldwide emissions of methane from rice paddies were 345 MMTCE (60 Tg) in 1994 (IPCC, 1995), with the highest emissions coming from China, India and Indonesia (EPA, 1994). The estimation of CH_4 budget from Indian paddy fields is of special significance as India has an area of about 42.24 m ha under rice cultivation.

Emission of metane from Indian rice field (IARI, 2005)

Water regime	Area (million ha)	Emission (Tg)
Upland	4.2	0.00
Rainfed low land	14.41	0.75
Irrigated low land	24.41	1.89
Deepwater	2.22	0.28
Total	42.24	2.92

India is currently the sixth largest and second fastest growing greenhouse gas contributor to climate change in the world. International studies based very limited measurement done in USA and Europe and extrapolated to the whole world indicated that as much as 110 Tg per year was released from rice paddies alone (Houghton *et al.,* 1990). Since India and China are major rice cultivators, US-EPA attributed the Indian rice field release 38 Tg methane per year. Agriculture sector contributes >65% to Indian methane emissions.

Methane fluxes in rice fields

Methanogenesis, the process responsible for methane formation, occurs in all anaerobic environments in which organic matter undergoes decomposition. Rice is generally grown in water logging condition, which creates an anoxic environment. It is conducive to methane production by the strictly anaerobic methanogenic bacteria. The methanogens use organic compounds as electron donors for energy and synthesis of cellular constituents, and in turn, reduce C to CH_4.

Methane is released from anaerobic wetland soils to the atmosphere through diffusion of dissolved methane, ebullition of gas bubbles, and *via* plants that, like rice, develop aerenchyma tissue. Large portions of methane formed in an anaerobic soil may remain trapped in the flooded soil. More than 90% of methane released from rice soil to the atmos-phere is emitted *via* the rice plant. The low solubility of methane in water limits its diffusive transport in the flooded soil and most methane is oxidized to carbon dioxide *via* methanol, formaldehyde and formate as it passes the aerobic soil-water interface. The release of methane by diffusion through the wet soil column is negligible in clayey soil, but it may become significant in sandy soils in which bigger pores between soil particles prevail. Most rice soils have high clay contents. Soil fauna, especially aquatic earthworms (Tubificidae), increase emission through diffusion and ebullition when they dig into the topsoil. At the same time, oxidation of methane is enhanced. In deepwater rice fields, diffusing methane may only be oxidized in the upper water column, because the soil-water interface and the lower water column may be anaerobic.

Two or three maxima of plant-mediated emission rates are generally observed in irrigated rice fields during the cropping season. Methane emission increases during the vegetative phase, sometimes with an early intermediate peak. It decreases after panicle initiation and increases again after flowering, before declining at the end of the season. For irrigated rice, methane emissions calculated as a function of rice produced are higher in the dry season than in the wet season. Various climatic, soil, water, and culture factors modify this general pattern. Methane emission is higher during *rabi* season compared to *kharif* season (Udayasoorian, 1995).

Thus rice plants in-fluence the methane dynamics in paddy soil by (1) providing substrate in the form of root exudates to methanogens and enhancing the production of CH_4; (2) transporting CH_4 from soil to atmosphere (conduit effect), and (3) creating aerobic microhabitat in rhizos-phere, which is suitable for growth and multiplication of methanotrophic bacte-ria

Methane flux in rice fields is affected by rice varieties, water level, fertilizer application and crop phenology. As far as ammonium-based fertilizer application is con-cerned, it has been a common assumption that it enhances the CH_4 emission due to increasing soil pH that stimulates methanogens. Most of the workers have argued that increase in CH_4 emission by rice plants in response to heavy fertilization would be a function of increased biomass production and carbon availability. Since all known methanogens use NH_4^+ as nitro-gen source, the stimulatory effect of ammonium-based fertilizer on CH_4 pro-duction is not surprising.

Mitigation options

The mitigation options include (1) form and dose of nitrogen and other chemical fertilizers, (2) the mode of fertilizer application, (3) water man-agement, and (4) cultivation practices. The mitigation option should be se-lected according to local circumstances because climate, type of paddy field and cultivation practices differ from place to place.

Water management

Water mangement is one of the most confounding factors affecting methane emission. The average emission in saturated soil was 0.3 to 0.6 kg per day while intermittent wetting and drying it was 0.1 to 0.4 kg per day. Intermittent irri-gation is an option for minimizing CH_4 emission. Increasing water percolation would add oxygen-rich water to the reduced soil layer and decrease methane production.

Effect of water regimes and N sources on methane emission from rice soils (IARI, 2005)

Water regime	Metahne emission (kg per ha)			
	Urea	Urea + FYM	Control	Mean
Saturated soil	28.05	45.36	24.27	32.56
Intermittent drying	14.60	27.72	8.28	16.87
Mean	21.33	36.54	16.28	

Nitrogen inhibitors

In addition, nitrification inhibitors have been shown to inhibit CH_4 emission. Nitrification inhibitors, such as nitrapyrin and acetylene, incorporated into the soil also limit methane production without reducing much methane oxidation. Nitrification inhibitors, which slow down the process of nitrification in soil, could reduce the emission of methane from soil.

Cultivars

The aerenchyma of rice plants mediate the transport of air (oxygen) to the roots and methane from the anaerobic soil to the atmosphere. The flux of gases in the aerenchyma depends on concentration gradients and diffusion coefficients of roots and internal structure, including openings of the aerenchyma. The number of tillers per area, the root mass, the rooting pattern, and metabolic activity also influence the gas fluxes. Oxygen diffusion and exudation of oxygen radicals combined with abundant methane-oxidizing bacteria result in oxidization of methane in the rhizosphere, whereas organic root exudates and root litter are a source of methane formation. Rice cultivars show pronounced variations in methane emission. Seasonal emission was maximum for Pusa 933 variety (24.2 kg ha^{-1}) and minimum for Pusa 169 (15.6 kg ha^{-1}) with intermediate values in the decreasing order of Pusa 1019, Pusa Basnati, Pusa 834 and Pusa 677 (IARI, 2005).

Fertilization

Ammonium sulphate is the eco friendly 'N' fertilizer, which reduces the methane flux (Udayasoorian, 1999). The application of neem coated urea, coated calcium carbide, neem oil and dicyandiamide (DCD) reduced the emission of methane. Application of sulphate-containing amendments is a mitigation option for reducing CH_4 emissions from rice fields (Van der Gon *et al.,* 2001). Sulphate-reducing bacteria compete with methanogens for the limited hydrogen, but the amount of sulfate normally added as fertilizer, seems to be insufficient to have significant effects.

Organic matter management

The topsoil (0-15 cm) contributes the major portion (99%) of the methane emission compared to the subsoil. Soil organic carbon and total N contents, texture and cation exchange capacity significantly affect methane emission. Amendments with fresh organic matter, such as the rice straw and green manures increase methane production and emission. Compost can be used as the best organic manure, which causes low emission without reducing grain and straw yields. *Sesbania rostrata* is the best source off green manure, which substantially reduces methane emission having comparable grain and straw yield with *S. aculeata* (Udayasoorian *et al.,* 1995). Application of composted material, which has a higher degree of humification marginally increases methane formation and fluxes. Improving organic matter management by promoting aerobic degradation through composting or incorporating into soil during off-season drained period is another promising technique (Kalra and Aggarwal, 1996). The application of farmyard manure (FYM) increases methane emission by adding organic carbon and N required for microbial activities and serving as a source of electrons. Substituting 50% of inorganic N with FYM increased the emission by 172% compared to the application of entire amount of N through urea. In another study, the emission of the methane was the lowest

(28.4 kg per ha) in the unfertilized treatment and the highest (41.3 kg per ha) with the application of the entire amount of N through organic sources. However, the application of biogas slurry reduced the emission by 2.3 times compared to FYM suggesting that the biogas slurry should be the preferred source over FYM for mitigating methane emission (IARI, 2005).

Culture practices

International Rice Research Institute (IRRI) suggest that soil disturbances caused by current culture practices release large amounts of soil-entrapped methane. The increased adoption of direct seeding (wet and dry seeding) instead of transplanting are likely to reduce methane emission. In direct-seeded rice, flooding periods are shorter and cultural disturbance of reduced soils is minimized.

Rice-based cropping systems

Crop diversification is a feasible option to reduce total methane emission and increase production as well as income (Neue *et al.,* 1991). Crop intensification through crop sequencing has become possible because early maturing varieties allow farmers to gain as much as 45 days in a growing season for additional crop production. Direct-seeded rice can be harvested 15-30 days earlier than transplants of the same variety.

Conclusion

The complex interactions among methane formation, methane oxidation, rice growth and cultivation, and methane emission require an immediate, integrated, and interdisciplinary research approach, including application of socioeconomics and participation of farmers, to achieve the knowledge needed to design feasible and effective mitigation technologies. With current cultivation technologies, methane emission from rice fields is expected to increase, as rice production has to be increased by 50 to 100% within the next three decades. By using a combination of feasible mitigation technologies, however, there is great potential to stabilize or even reduce methane emission from rice fields while increasing rice production, without dramatically changing culture practices.

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