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Special Topic

Do paddy soils of Sri Lanka emit excessive amounts of methane? - A potent greenhouse gas (GHG) responsible for global warming and climate change

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Abstract: Paddy soils are considered as a major source of methane (CH_4), which is the second most important atmospheric greenhouse gas (GHG) after the carbon dioxide. Estimation of methane flux from paddy soils in a given country mainly depends on its total extent of paddy lands. Further, a variety of other edaphic and agronomic factors such as redox potential of the soil, soil reaction, organic matter content, soil temperature, rice variety or cultivar, water management, fertilizer application, and more importantly the population sizes of methanogens, methantrophs and other competitive bacteria contributes to the CH_4 flux from paddy soils. This paper proposes that estimation of methane emission from paddy soils in Sri Lanka should be region-specific as the foregoing edaphic and agronomic factors are highly spatially variable in 46 agro-ecological regions (AERs) of the country, out of which paddy is cultivated in 40 AERs.

Keywords: Climate change, Greenhouse gas (GHG) emission, Paddy soils, Sri Lanka

Introduction

Methane (CH_4) is the second most important atmospheric greenhouse gas (GHG) after CO_2 and is believed to account for 17% of global warming (IPCC, 2013). The methane concentration of the atmosphere in 2019 has reached an all-time high level of 1,875 ppb, which is 2.5 times higher than its pre-industrial value (NASA, 2019). Methane strongly absorbs and emits infrared radiation (with a great warming potential) at bands of wavelengths where CO_2 and water vapor do not absorb (Wang *et al.*, 1976). Paddy soils, enteric fermentation, landfills and natural wetlands are considered as sources of methane flux to the atmosphere out of which the quantification of the methane from paddy soils can only be given with a high range of uncertainty. This is mainly due to the diverse physical, chemical and biological fertility status of paddy soils across different agro-ecological regions in the world. For example, the fertility parameters of paddy soils in Mekong Delta, where a vast extent of paddy soils exist and known as the "Paddy bowl of the world", are not comparable with paddy soils of an island nation like Sri Lanka where soil formation and subsequent profile development is quite different. This is mainly due to that the emission of methane from paddy fields to the atmosphere includes methane production (methanogenesis) in soil by methanogens, methane oxidation (methanotrophy) by methanotrophs and vertical transfer of methane via plant-mediated transport, diffusion and ebullition (gas transport as gas bubbles). All such mechanisms are highly dependent on physical, chemical and biological properties of paddy soils in a given location.

The Initial National Communication of Sri Lanka submitted to the UNFCCC has shown that rice production of Sri Lanka accounts for methane emission of 21 Gg/year, which is equivalent to 13.4% of the GHG emissions from agriculture sector or 0.02% of all GHG sources from Sri Lanka (MoE, 2000). This calculation was based on the global default emission factors given in the GHG calculation guidelines of IPCC (2006). These values were revised in the Second National Communication (MoE, 2011) and it was estimated that rice accounts for 185 Gg/year, which is about 63.2% of emissions from agriculture sector and 0.02% of total GHG emissions in Sri Lanka (note that the total emissions have increased). However, it is noteworthy that these national GHG inventories do not provide data for specific regions at sub-national scale or agro-ecological region levels of Sri Lanka where the edaphic features of paddy soils are highly diverse. This paper thus intends to address the issue whether the estimated methane flux from paddy soils in Sri Lanka would adequately represent the actual situation of paddy soils in the country.

Factors affecting methane emissions from paddy soils

Methane production or methanogenesis in the anaerobic layers of paddy soils occurs by decomposition of organic matter by Methanogens (Dubey, 2001). Methanogens are known to be strictly anaerobic unicellular organisms belonging to a separate phylogenetic domain called *archae* (Garcia, 1990). However, Conrad (2020) reported that they can also tolerate O_2 to some extent and thus survive desiccation of flooded soil environments amazingly well. Methane is derived mainly from plant-borne materials present in paddy soils, and organic manure (Dannenberg and Conrad, 1999), if applied. Conversion of organic matter to methane in paddy fields follows the sequential reduction of oxygen, nitrate, manganese, iron and sulfate, which serve as electron acceptors for oxidation of organic matter into carbon dioxide under anaerobic conditions (Conrad, 2020; Yao *et al*. 1999). Hence, methanogenesis is the last step in the anaerobic degradation of organic matter in paddy soils.

Redox potential (Eh) and soil reaction (pH)

Methanogenesis in paddy soil is controlled by many factors. Out of them, soil redox potential (Eh) and soil pH are considered as the critical controls. Wang *et al*. (1993) and Patrick (1981) have shown that the critical soil Eh for initiation of methane production is approximately between -150 to -160 mV. However, the soil Eh, (at values between -230 and -150 mV), shows a negatively exponential relationship with methane production (Equation 1).

$$Y = a10^{-bx} \text{ --------------------- Equation 1}$$

where Y is the methane production rate, μg g^{-1} d^{-1}; x the soil Eh, mV; and a and b are constants.

They further reported that the optimum soil pH range for methane production is between 6.7 and 7.1. A marginal decrease in pH resulting from the introduction of acidic materials have significantly decreased the methane production, while a slight increase in soil pH, (*i.e.* about 0.2 units higher than the natural soil suspension pH) has resulted in an enhancement of methane production by 11% to 20% and 24% to 25% at controlled Eh levels of -250 and -200 mV, respectively (Wang *et al*., 1993). Conrad (2020) also reported that drainage and aeration may turn flooded soils into sinks for atmospheric methane, probably due to the specific characteristics of the resident methanotrophic bacteria who are responsible for oxidizing methane in flooded paddy soils. Therefore, it is important to carry out a comprehensive assessment on the redox potential of paddy soils in Sri Lanka across all agro-ecological regions, before commenting on the amount of methane emitted by the paddy soils in Sri Lanka. It is even erroneous to conclude that that paddy soils of Sri Lanka emits excessive amount of methane. Furthermore, Neue *et al*. (1996) have shown that changes in water management, nutrient management, cultural practices, and cultivar selection can regulate the natural capacity of emitting methane from paddy soils while maintaining the rice production and productivity.

Organic amendments

The time until the onset of methane production and the magnitude of production is a function of the quantity of easily degradable organic matter, reducible Fe and Mn and sulfate (Yao and Conrad, 1999). Nevertheless, the methanogens have to compete for available substrates with other anaerobic bacteria, namely, nitrate, manganese, ferric iron and sulfate reducers. Thus, in addition to the mechanism of Methanogenesis in paddy soils, the information regarding population size of methanogenic, other competing anaerobic bacteria and methanotrophs in paddy fields are important determinants of methane production. Therefore, relative organic matter content of paddy soils and availability of other electron acceptors, population size of Methanogens, other competing anaerobic bacteria, and methanotrophs in a given paddy soil determine the methane flux from a paddy tract to the atmosphere, but, not the extent of paddy soils in a given geographical region.

Organic amendments of flooded soils increase methane production and emission (Schiitz *et al*., 1989; Cicerone *et al*., 1992) owing to the lowering of Eh and increasing carbon sources for Methanogens. It has also been found that addition of rice straw at the rate of 5 t/ha increased the methane emission by ten-fold compared to mineral fertilizer application. According to Dubey (2005) and Conrad (2020), organic materials influence the methane formation through changes in qualitative and quantitative properties of soil.

Rice variety/cultivar

Rice plants play an important role in methane emission in paddy soils. Plant mediated transport is the primary mechanism for the methane emission in paddy fields, and this amount contributes 60-90% to the total CH_4 emission. In the temperate paddy fields, more than 90% of the methane is emitted through plant mediated transport (Schultz *et al*., 1990) while in the tropical paddy fields, significant amounts of methane may evolve by ebullition, in particular during the early period of the season and in case of the high organic input (Denier van der Gon and Neue, 1995). Ebullition is also the common and significant mechanism of methane flux in natural wetlands (Wassmann and Martius, 1997). Thus, the production and transport of methane to the atmosphere depend on properties of the rice plant as well as organic inputs. Well-developed intracellular air spaces (aerenchyma) in leaf blades, leaf sheaths, culm, and roots provide an efficient gas exchange medium between atmosphere and anaerobic paddy soil.

Hence, it is very clear that a significant variation in methane emission from different paddy tracts should exist where different rice varieties or cultivars are grown. Schlitz *et al*. (1989) have revealed that an Italian traditional rice variety "*Dular*" has emitted about 30% more methane per day than did the new plant type IR-65597. The traditional varieties have more tillers and longer roots which might have contributed to enhance methane emission. Nevertheless, according to Wang *et al*. (1993) cultivars influence the methane emission by providing the soil with root exudates, decaying root tissues and leaf litter.

Cultural practices

Water management is one of the most important factors in rice production, especially where irrigation water supply is not assured and also in rice eco-systems with frequent drought conditions. Even with irrigated rice, short aeration period at tillering has been shown to increase yield (Schlitz *et al*., 1989). With respect to methane emission, it was shown that a single mid-season drainage may reduce seasonal emission rates by about 50% (Sass *et al.*, 1992; Kimura, 1992). Ma and Lu (2011) and Yagi *et al*. (1996) also reported that intermittent drainage is a promising strategy in paddy cultivation to mitigate methane emission. Drainage dramatically changes the physicochemical conditions of flooded paddy soils, for example, increasing diffusion rate of gases and availability of oxygen.

Ma and Lu (2011) revealed that intermittent drainages resulted in both a decrease of Methanogens and an increase of Methanotrophs population density, being partially responsible for the reduction of methane emission from paddy fields. Under local context of paddy cultivation, this is a common situation in both rainfed and irrigated rice-ecosystems during *Yala* season (March-September) and rainfed rice eco-systems during *Maha* (October-February) seasons.

Methane oxidation

Methane emission from a rice field is the net effect of methanogenesis and methanotrophy. Most of the methane produced in paddy soils are oxidized by methanotrophs at the soil surface (Yun *et al*., 2013; Conrad, 2007). It has been found that more than 90% of the methane produced in the anaerobic environments of paddy fields can be re-oxidized by methanotrophs in the aerobic zones (Wassmann *et al*., 1993; Oremland *et al*., 1992; Sass *et al*., 1991). Further, Le Mer and Roger (2001) have shown that depending on the period of the crop cycle and the water management, the percentage of the methane produced that is oxidized by methanotrophs varies from 0 to 97%. Based on the investigations in the paddy field of Texas in USA, Sass *et al*. (1991) have shown that about 70% of the methane produced was re-oxidized during the maximum methane production under continuous irrigation. Thus, it is clear that in paddy fields, variations in methane emission are mostly attributed to variations in methanotrophs' activity rather than the methanogenesis (Sass *et al*., 1990; Schlitz *et al.*, 1989).

Soil temperature

Soil temperature is known to be an important factor in affecting the activity of soil micro-organisms. Because the conversion rate of substrate to methane depends on the temperature. Yamane and Sato (1961) have found that methane formation reached a maximum at 35 °C in waterlogged alluvial soils while the rate of methane formation was very small below 20 °C. During the *Maha* season, soil temperature of paddy soils even in the Dry zone of Sri Lanka hardly reaches 35 °C and the same remains true for Wet and Intermediate zones during both *Yala* and *Maha* seasons.

Are there paddy soils in Sri Lanka with high organic matter contents?

Most of the paddy soils in Sri Lanka are moderately to imperfectly drained soils, especially in the lands come under Mahaweli and other recent irrigation development schemes such as Kirindi Oya, Deduru Oya, Yan Oya, etc., which are being considered as high potential areas for paddy production in the country. Even in other high potential areas, such as in the Eastern province (*i.e.* Gal Oya) the Eh levels may be conducive (Eh < -150 mV, in poorly drained soils) for methane emission, however, they are low in organic matter. Thus, the estimation of methane emission estimates blankly depending on the extent of paddy lands could be far from the reality. There are about 25-30% of paddy lands (about 250,000 ha of a total of 870,000 ha) in the Wet zone of Sri Lanka. Out of which, 58,000 ha are classified as Bog and Half-bog soils (Table 1) where organic matter content is above 15-20%. These are the soils that are usually considered as methane emitting paddy soils in Sri Lanka owing to their high organic matter content and the state of reduced conditions (< -150 mV). However, almost all these Bog and Half-bog soils found in the Wet zone are mainly limited to the Colombo and Kalutara (Western province) and Galle and Matara districts of the Southern province (Table 1).

Meanwhile, even though they have been categorized as paddy lands at present, most of these lands are now abandoned for decades due to several hydrological and socio-economic reasons. They are now merely wetlands without human disturbances. Thus, it is not correct to account the plant-mediated methane emission to atmosphere from these lands as emissions of paddy soils in the absence of paddy cultivation there in. Hence, if aforesaid all the 58,000 ha of lands (about 580 km^2, Table 1) to be considered for estimating methane emission, the only possibility is to account as ebullition (mainly) and diffusion (marginally), the mechanisms occur commonly in methane flux in natural wetlands, as pointed out by Wasuman and Martius (1997). However, in a wetland, the methane trapped in the reduced layer of soil comes out of the soil-water-atmosphere interface when and only when the soil is disturbed. But, these abandoned paddy lands are out of human interference and unlikely to be disturbed. In most cases. Therefore, even ebullition could be excluded as a significant mechanism for methane emission from these lands in the Wet zone, and hence, correct estimates are crucially important.

Table. 1 Spatial distribution of Bog and Half-bog soils in Sri Lanka

Province	**District**	**Area (km²)**
Western	Colombo	68.12
Western	Gampaha	34.81
Western	Kalutara	173.32
Southern	Galle	204.81
Southern	Matara	78.47
Sabaragamuwa	Ratnapura	20.29
	Total	579.82

Source: Natural Resource Management Center, Department of Agriculture, 2020

In the backdrop of all the scientific evidence presented above, we propose that the methane emission factors from paddy soils in Sri Lanka has to be region specific where the edaphic factors are considerably different from each other across agro-ecological regions of the country. Hence, a comprehensive analysis of the paddy soils is essential considering the redox potential, organic matter content, soil temperature regime, abundance of other electron acceptors and more importantly, the population size of relevant soil microbes, *i.e.*, methanogens, Methanotrophs and other competitive bacteria, in paddy soils in Sri Lanka.

References

Cicerone R.J., Delwiche C.C., Tyler S.C. and Zimmermann P.R. (1992). Methane emissions from California rice paddies with varied treatments. *Global Biogeochemical Cycles*, 6: 233-248.

Conrad R. (2020). Methane Production in Soil Environments - Anaerobic Biogeochemistry and Microbial Life between Flooding and Desiccation. *Microorganisms*, 8: 881.

Conrad R. (2007). Microbial ecology of Methanogens and Methanotrophs. *Advances in Agronomy* 96: 1–63.

Conrad R. and Rothfuss F. (1991). Methane oxidation in the soil surface layer of a flooded rice field and the effect of ammonium. *Biology and Fertility of Soils*,. 12: 28-32.

Dannenberg S. and Conrad R. (1999). Effect of rice plant on methane production and rhizospheric metabolism in paddy soil. *Biogeochemistry*, 45: 53-71.

Denier van der Gon H.A.C. and Neue H.U. (1995). Influence of organic matter incorporation on the methane emission from a wetland rice field. *Global Biogeochemical Cycles*, 11: 11-22.

Dubey S.K. (2005). Microbial ecology of Methane emission in rice agro-ecosystem: A review. *Applied Ecology and Environmental Research*, 3(2): 1-27.

Dubey S.K. (2001). Methane emission and rice agriculture. *Current Science*, 81: 345 - 346.

Garcia I.L. (1990). Taxonomy and ecology of methanogens. *FEMS Microbiology Letters*. 87(3-4):297 - 308

IPCC (2013). Contribution of Working Group I to the Fifth Assessment Report of the Inter-governmental Panel on Climate Change. (Stocker T.F. *et al*. Eds.), pp. 465–570. Cambridge Univ. Press.

IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories, *The National Greenhouse Gas Inventories Programme* (Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. eds). Published: IGES, Japan.

Kimura M. (1992). Methane emission from paddy soils in Japan and Thailand. In: *World Inventory of Soil Emission Potentials* (Batjes N.H. and Bridges E.M. eds), pp. 43-79. WISE Report 2, ISRIC, Wageningen.

Le Mer J. and Roger P. (2001). Production, oxidation, emission and consumption of methane by soils: A review. *European Journal of Soil Biology*, 37 (2001): 25-50.

Ma, K. and Lu Y.H. (2011). Regulation of microbial methane production and oxidation by intermittent drainage in rice field soil. *FEMS Microbiology Ecology*, 75: 446-456.

MoE (2011). GHG inventory. Second National Communication - submission to the UNFCCC. Climate Change Secretariat, Ministry of Environment, Government of Sri Lanka.

MoE (2000). GHG inventory. Initial National Communication - submission to the UNFCCC. Climate Change Secretariat, Ministry of Environment, Government of Sri Lanka.

NASA (2019). Methane emissions continue to rise. https://earthobservatory.nasa.gov/images/146978/methane-emissions-continue-to-rise (Accessed on 28th November 2020)

Neue H.U, Wassmann R., Lantin R.S., Alberto M.A.C.R. Aduna J.B. and Javellana A.M. (1996). Factors affecting Methane emission from rice fields. *Atmospheric Environment*. 30 (10/11): 175

Neue H.U. and Roger P.A. (1994). Potential of methane emission in major rice ecologies, In: Zepp R.G. (Ed.), pp. 65-93. Climate Biosphere Interaction: Biogenic Emissions and Environmental Effects of Climate Change, John Wiley and Sons.

Oremland R.S. and Culbertson C.W. (1992). Importance of methane-oxidizing bacteria in the methane budget as revealed by the use of a specific inhibitor. *Nature*, 356: 421-423.

Patrick W.H. Jr (1981). The role of inorganic redox systems in controlling reduction in paddy Soils. In: *Proceedings of the Symposium on Paddy Soils*, Science Press, Beijing, Spring Verlag, pp. 107–117.

Sass R.L., Fisher F.M., Wang Y.B., Turner F.T. and Lund M.F. (1992). Methane emission from rice fields: the effect of floodwater management. *Global Biogeochemical Cycles*, 6:249 - 262.

Sass R.L., Fisher F.M., Harcombe P.A. and Turner F.T. (1991). Mitigation of methane emissions from rice fields: possible adverse effects of incorporated rice straw. Global *Global Biogeochemical Cycles*, 5: 275-287.

Sass R.L., Fisher E.M., Harcombe P.A., Turner E.T. (1990). Methane production and emission in a Texas rice field. *Global Biogeochemical Cycles*, 4: 47-68.

Schlitz H., Holzapfel-Pschorn A., Conrad R., Rennenberg H. and Seller W. (1989). A three-year continuous record on the influence of daytime, season, and fertilizer treatment on Methane emission: rates from an Italian rice paddy field. *Journal of Geophysical Research*, 94(16): 405-416.

Wang J., Bogena H.R., Vereecken H. and Brüggemann N. (2018). Characterizing redox potential effects on greenhouse gas emissions induced by water-level changes. *Vadose Zone Journal*, 17:170152. DOI:10. 213 6/vzj2017.08.0152.

Wang Z.P., Delaune R.D., Patrick W.H. Jr., and Masscheleyn P.H. (1993). Soil Redox and pH Effects on Methane Production in a Flooded Rice Soil. *Soil Science Society of America Journal*, 57(2): 382-385.

Wang W.C., Yung Y.L., Lacis A.A., Mo T. and Hansen J.E. (1976). Greenhouse effects due to man-made perturbations of trace gases. *Science*, 194: 685-690.

Wassmann R. and Martius C.S. (1997). Methane emission from the Amazon flood plain. In: Junk W.J. (Ed.). The Central Amazon Floodplain: *Ecological Studies*, 126: 137-143

Wassmann R., Papen H., and Rennenberg H. (1993). Methane emission from rice paddies and possible mitigation strategies. *Chemosphere*, 26: 201–217.

Yagi K., Tsuruta H., Kanda K. and Minami K. (1996). Effect of water management on methane emission from a Japanese rice paddy field: automated methane monitoring. *Global Biogeochemical Cycles*, 10: 255-267.

Yamane I. and Sato K. (1961). Effect of temperature on the formation of gases and ammonium nitrogen in the water-logged soils. *Science Reports of the Research Institutes, Tohoku University*, 12: 1-46.

Yao H. and Conrad R. (1999). Thermodynamics of methane production in different rice paddy soils from China, the Philippines and Italy. *Soil Biology and Biochemistry*, 31: 463-473.

Yao H., Conrad R., Wassmann R. and Neue H.D. (1999). Effect of soil characteristic on sequential reduction and methane production in sixteen rice paddy soils from China, the Philippines, Italy. *Biogeochemistry*, 47: 269-295.

Yun J., Yu Z., Li K., and Zhang H. (2013). Diversity, abundance and vertical distribution of methane-oxidizing bacteria (Methanotrophs) in the sediments of the Xianghai wetland, Songnen plain, northeast China. *Journal of Soils and Sediments*, 13: 242–252.