

Emission of Methane From Wetland Paddy Fields: A Review

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Received June 15, 2022; revised and accepted July 5, 2022

Abstract: Cultivation of rice is widely practiced throughout the world as rice is a staple food for half of the world's population. However, the emission of methane (CH₄) is an issue associated with the cultivation of rice. Many reports on the level of CH₄ emission after treatment of different kinds of organic materials in paddy fields were reported. It was observed that the application of a combination of tested locally available compost along with inorganic NPK fertilisers effectively reduced the rate of emission of CH₄. Intermittent wetting and drying in addition to the combined application of compost and NPK fertilisers will help in reducing the emission of CH₄ up to 40 to 45%. To undertake an intermittent drainage system is a difficult step for the farmers to implement as it has extra cost and labour. Therefore, lawmakers should initiate steps to help farmers in order to reduce the emission of CH₄ from paddy fields.

Keywords: Chemical fertiliser; Compost; Manure; Intermittent irrigation.

Introduction

Methane (CH₄) is a colourless, odourless and highly flammable gas. It absorbs infrared radiation and reradiates it back to the earth's surface making it a potent greenhouse gas. It is the second most important greenhouse gas after CO₂ that contributes to global warming. CH₄ has a very high global warming potential which is 34 times more than carbon dioxide (IPCC, 2013), and is responsible for 1/3rd of global warming. The atmospheric concentration of CH₄ reached an average of 1889 ppb which exceeds 262% of the pre-industrial level (WMO, 2021). Agriculture is the main source of anthropogenic CH₄ emission (UNEP, 2021) accounting for 43% of the net emission (Shang et al., 2021). Emission from paddy fields contributes about 20% of the total global CH₄ emission (Forster et al., 2007). India is among the top ten emitters of

CH₄ emission which emits 6.08 Tg and whose share is approximately 10% of the total emission (Crippa et al., 2020). CH₄ is produced by the action of methanogens-the bacteria when they decompose organic substrates in anaerobic conditions provided by flooded conditions in paddy fields. CH₄ that is left after the oxidation process reaches the atmosphere by diffusion, ebullition or by plant-mediated transport through the aerenchyma (Mer and Roger, 2001).

In India, rice cultivation is widely practiced throughout the country for food as well as for economic sustainability. Half of the world's population depends on rice for their calorie intake. In order to meet the demand of the growing population, the production of rice is estimated to increase by 24% in the year 2030 (FAO, 2009). People extensively use synthetic fertilizers to get higher yields. It not only deteriorates the soil quality but also increases CH₄ emission from the field (Wassmann

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et al., 2009) which increased by an average of 3.9% per year from 1961-2010 (Tubiello et al., 2013). Numerous studies have reported that the emission of CH_4 from paddy fields can be reduced through modification of fertiliser application rates, type of fertiliser amendment (Zheng et al., 2012; Kong et al., 2019) and water management (Hou et al., 2012; Zhang et al., 2016; Souza et al., 2021). Through improved management practices the paddy fields can also act as a sink for CH_4 by sequestering carbon in the soil (Smith et al., 2008). Therefore, there is an urgent need to implement the mechanisms for reducing the emission of CH_4 without affecting crop yield. Attention has been shifted towards the use of organic fertiliser due to their beneficial effect on soil and less impact on human health. However, some studies reviewed that the use of organic materials or fertilisers enhances CH_4 emission from paddy fields (Kong et al., 2019; Fauzan et al., 2021).

Reducing the amount of CH_4 emissions will really help in countering global warming because CH_4 has a lifespan of 12.4 years whereas the lifespan of CO_2 has hundreds to thousands of years. Therefore, reducing CH_4 emissions from all sources by taking up different measures will help in achieving the goal of limiting the rise in global temperature up to 1.5°C under the Paris Climate Change Agreement.

In the present review, the authors sought to make a comparative study on the level of CH_4 emission due to organic and chemical fertiliser amendment in paddy fields and the effect of the water regime in order to propose a suitable method of reducing the emission of CH_4 .

Organic Fertiliser and CH_4 Emission

In a study conducted by Hwang et al. (2017) in paddy fields at Jinju, South Korea it was observed that in the control plot where the standard level of chemical fertilisers was applied, emission of CH_4 was recorded to be 220 kg ha^{-1} whereas, in the green biomass of barley and hairy vetch treated plot, a drastic increase in CH_4 emission with 904 kg ha^{-1} was recorded. Although a slight increase in grain yield was recorded in the green biomass treatment, they have suggested the application of composted biomass in place of green biomass to reduce the emission of CH_4 from paddy fields. Wang et al. (2021) also applied digested Chinese milk vetch in place of fresh biomass before rice transplanting and the process led to reduced availability of labile C source for the methanogens and control reduction of Eh (redox potential of soil). Therefore, application of the digested Chinese milk vetch compost led to the

emission of only 34.74 kg ha^{-1} of CH_4 compared to straw incorporation ($118.08 \text{ kg ha}^{-1}$) and without organic amendment (48.21 kg ha^{-1}). Treatment with compost of *Azolla caroliniana* a tiny floating aquatic fern led to 1.1 to 1.4 fold greater soil carbon sequestration and more grain yield compared to the treatment of cow dung and green manure (*Sesbania aculeata*) in Northeast India. It also suppressed the emission of CH_4 by 30-36% due to the enhancement of porosity, C-storage and recalcitrant C fractions of soil (Bharali et al., 2021).

Treatment with indigenous organic fertiliser could be a viable option for reducing CH_4 emission, getting a good quality grain yield and reducing the use of inorganic fertiliser. Soebandion et al. (2021) observed treatment of indigenous banana hump liquid organic fertilizer and bamboo root liquid organic fertiliser generate CH_4 1.001 times compared to no fertilizer treatment. Whereas, inorganic fertiliser and cow manure treatments emit CH_4 1.952 and 1.884 times the no fertiliser treatment. Jeong et al. (2018) observed that the application of commercial biofertiliser has lower emission of 0.954 times than no fertiliser treatment. Utilisation of composted swine manure decreased the global warming potential by 25% over application of the fresh swine manure. During the process of composting, a 35% increase in global warming potential was observed, however, there was a reduction in CH_4 emission by 60% due to utilisation of compost overcome by emission during its utilisation. Therefore, the application of compost is a good management strategy to reduce CH_4 emissions from rice fields (Jeong et al., 2018). Haque et al. (2021) observed that the application of vermicompost reduced CH_4 , CO_2 and N_2O flux by 13-19%, 17-21% and 4-9%, respectively, compared to the treatment of fresh cow manure. Vermicompost and cow manure treatment significantly increased the grain yield compared to the application of chemical fertiliser alone although emission of CH_4 was lower in the chemical fertiliser. Maximum emission of CH_4 was recorded from the treatment of non-composted manure with $47\text{-}61 \text{ mg/m}^2$. The application of rapidly and commonly composted cattle manure decreased the CH_4 emission by 44.4 and 91.0%, respectively, compared to non-composted manure. The result also indicated that the application of fresh non-composted manure leads to an increase in emission of CH_4 although the grain yield may be enhanced. The number of methanogens in the rapidly and commonly composted cattle manure treatment was the lowest leading to a lower CH_4 emission (Zhou et al., 2016).

In spite of using fresh manure alone experiments in combination with other materials were also conducted. Fauzan et al. (2021) performed an incubation study to determine the effectiveness of chicken manure combined with steel slag at different ratios to mitigate CH_4 emissions from paddy fields. The treatment of chicken manure and steel slag in the ratio of 1:2.5 emitted the lowest cumulative CH_4 with a value of $0.01 \text{ mg C kg}^{-1} \text{ Period}^{-1}$. The study revealed that amendment of steel slag with chicken manure at a higher rate reduced CH_4 emission since iron content in the steel slag helped in inhibiting CH_4 production. Amendment of *Azolla*-cyanobacteria with phosphogypsum was also found to reduce by 29.7% and 32.6% of cumulative seasonal CH_4 emission in Japan and Bangladesh, respectively, compared to sole chemical fertilizer treatment. The *Azolla*-cyanobacteria inoculation improved soil redox potential thereby increasing oxidation of CH_4 , and reducing its emission (Ali et al., 2015).

In a study conducted by Yuan et al. (2018) in Shanghai, China, it was observed that the application of organic fertiliser leads to a maximum rate of CH_4 emission with $145.31 \text{ kg ha}^{-1}$ compared to a combined treatment of organic and chemical fertiliser (84.62 kg ha^{-1}), chemical fertiliser only (77.88 kg ha^{-1}) and no fertilisation (32.19 kg ha^{-1}). The treatment with organic fertiliser enhances soil nutrients, carbon, nitrogen, phosphorus and potassium and soil humic acid. Thereby, the potential of methanogens in paddy soil to produce CH_4 could be enhanced. Combined treatment of organic and chemical fertiliser partially mitigated CH_4 emission and also guaranteed a higher grain yield; therefore, they recommended the process of mixed fertilisation. According to Bharali et al. (2017), the incorporation of *Azolla* compost along with recommended NPK significantly increases the soil carbon storage capacity and improves crop yield by 27.3% over the control treatment (no fertiliser). However, its application resulted in enhancing methane emissions by 15.66% higher than the control. Das and Adhya (2014) observed that a combined application of manure and urea-N at a ratio of 1:3 produced $185.24 \text{ kg ha}^{-1}$ of CH_4 providing a 63.4% increase compared to control (no treatment) and 65.1% increase in crop yield compared to control. The treatment of urea-N fertiliser alone leads to an emission of 149.64 which was only 31.9% more than control and the crop yield was 38.5% higher than control. A combination of 0.5 t ha^{-1} of vermicompost with a recommended dose of chemical fertilisers was proposed as it reduced 37-77% of CH_4 emission compared to chemical fertiliser application and it also gives a 5%

higher grain yield of rice over sole chemical fertilisation (Haque and Biswas, 2021).

From the information collected it can be observed that the application of fresh manure and green manure alone in paddy fields led to an increase in emission of CH_4 . The application of locally available indigenous compost and vermicompost combined with chemical fertilisers is a good option for reducing the emission of CH_4 from paddy fields. Trials of locally available compost should be performed and tested under the field condition, before actual application by the farmers, to record the reduction in CH_4 emission. Utilisation of phosphogypsum and iron-containing wastes like steel slags along with compost also reduces the emission of CH_4 .

Chemical Fertiliser and CH_4 Emission

The application of chemical fertilisers in paddy fields is a normal process that is performed to increase the yield in order to meet the growing demand. Fertilisation provides nutrients to plants to improve their growth and yield (Moe et al., 2019). The influence of nitrogen fertilisation on CH_4 emission is difficult to predict since it shows either positive, negative or no effect at all (Cai et al., 2007). Some studies suggest that nitrogen fertiliser application decreased emissions of CH_4 during the rice growing seasons compared to no nitrogen fertiliser. For instance, the amount of annual cumulative CH_4 emission was lowest in the nitrogen fertiliser treatment plot with $793.8 \text{ kg CH}_4\text{-C ha}^{-1}$ while the highest emission ($882.8 \text{ kg CH}_4\text{-C ha}^{-1}$) was found in no nitrogen fertiliser plot (Zhou et al., 2018).

Shang et al. (2011) have reported that compared with control, NK fertiliser application slightly increased the net annual global warming potential, whereas NP and NPK fertiliser application decreased the greenhouse gas index by 23-29%. Therefore, they suggested a balanced P fertiliser supplement to reduce CH_4 emission and increase grain yield.

Datta et al. (2013) investigated the effect of chemical fertilisers on CH_4 emission from tropical rice fields of India. It was observed that the plots treated with N-fertiliser showed the highest amount of CH_4 emission with 80.27 kg ha^{-1} and $451.27 \text{ kg ha}^{-1}$ during the dry season and wet season, respectively. Minimum CH_4 emission was recorded from the NPK treatment plots in both dry (34.60 kg ha^{-1}) and wet seasons ($233.66 \text{ kg ha}^{-1}$). The result indicated that the application of P and K fertiliser help in developing aerenchyma of plant and stimulated the growth of methanotrophs – the bacterial population which increases oxidation of CH_4 in the soil.

Yang et al. (2012) also reported a lower CH_4 emission from NPK fertiliser applied to paddy fields compared to only N-fertiliser plots. Troare et al. (2017) again reported a minimum emission of CH_4 by the application of NaNO_3 fertiliser when compared to other types of chemical fertiliser application.

The average emission of CH_4 in the different growing stages due to the application of chemical fertilisers was calculated from the literature cited and represented in Figure 1. Emission from different kinds of treatment could not be depicted graphically although the range of reducing the emission of CH_4 could be established. The growing stage of paddy can be classified as 1. Vegetative growth stage: ranging from 0 to 49 days after transplantation (DAT) 2. Reproductive stage: 4 weeks (50 to 78 days) and 3. Ripening stage: 4 weeks (79 to 107 days). During the three stages, the maximum emission was observed in the reproductive stage and the minimum in the vegetative growth stage.

A total emission rate was $9.37 \text{ mg m}^{-2} \text{ hr}^{-1}$ as shown in Figure 1. Total emission during the 107 days of the active growth period was $24062.16 \text{ m gm}^{-2}$ and it comes to approx. 240 kg ha^{-1} . The total rice growing area of the world according to FAO (2011) is 161,420,743 ha. Therefore, the total average global emission of CH_4 during a rice growing season comes to 39 million tonnes (Tg) which is comparable to the range of 20 to 100 T gyr^{-1} with an average of 60 Tg, the data as provided by IPCC (1996).

Water Regime and CH_4 Emission

Water management acts as an important strategy to mitigate emissions of CH_4 from paddy fields. Haque

et al. (2016) studied the effect of two different water regimes – intermittent drainage and continuous flooding on CH_4 emission. They observed that intermittent drainage reduced the CH_4 emission rate by 54-58% compared to continuous flooding. Pramono et al. (2022) also observed that alternate wetting and drying reduced 14-18% of CH_4 emission and increase 6-7% grain yield compared to continuous flooding

Hadi et al. (2010) reported that the use of intermittent drainage increased the redox potential of soil in both Indonesia and Japan, limiting CH_4 emission without significantly changing the soil microbial population. The amount of CH_4 emitted from alluvial paddy soil of Indonesia and Japan due to continuous flooding was 1384 and $632.2 \text{ kg C ha}^{-1} \text{ season}^{-1}$, respectively. The study identified that the practice of intermittent drainage helped in reducing approximately 37% of the CH_4 emission. Shang et al. (2011) also reported similar positive results due to intermittent drainage patterns.

In another study by Hou et al. (2012), intermittent irrigation has proved to reduce the CH_4 emission by 81.8%, compared to continuous irrigation. Hwang et al. (2017) also reported that intermittent irrigation reduced CH_4 emission from compost-treated paddy fields by 37% on an average across sites without affecting the grain yield compared to continuous flooding. Alternate wetting and drying irrigation reduce greenhouse gas emissions due to more diffusion of atmospheric O_2 into the soil, thereby reducing the formation of CH_4 (Yang et al., 2012). An increase in N_2O emission may be slightly more due to increased nitrification of NH_4^+ during the dry period and denitrification of NO_3^- during re-wetting of dry soils. However, decreasing the emission

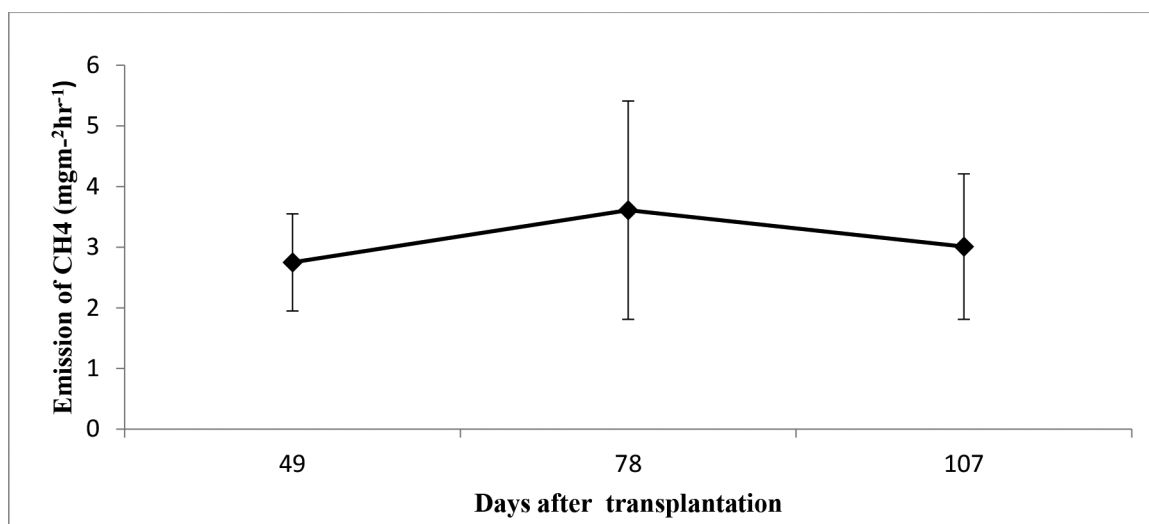


Figure 1: Average emission of CH_4 during the three growth stages of paddy due to application of chemical fertiliser.

of CH₄ from rice cultivation is the most effective way to mitigate global warming potential in rice cultivation as 15-20% of the total global emission of CH₄ is from paddy fields and total N₂O emission from all sources is responsible for only 6% in enhancing global warming (Abbassi et al., 2019).

Souza et al. (2021) revealed that the timing of drainage from paddy fields is important in reducing CH₄ emissions as optimal drainage timing maximises the mitigating efficiency of the drainage. For compost amended field, the average optimal wetting should be from 20 and 50 days after transplantation and it decreased 45% and 35% CH₄, respectively. Intermittent drainage reduced the logging of soil with water, which will enhance soil oxidation capacity thereby reducing CH₄ emissions.

Mitigation Measures

The total global emission of CH₄ was 590 Tg in 2019 out of which 230 Tg (40%) was from natural sources and 360 (60%) from anthropogenic sources (IEA, 2022). The average emission from paddy fields was 60 Tg (16%) according to IPCC (1996) and 39 Tg in the present review due to the application of chemical fertilisers. From the literature reviewed, it was observed that the application of compost/vermicompost mixed with chemical fertilisers reduced the emission of CH₄ from 29.7% (Ali et al., 2015) to 57% (Haque and Biswas, 2021). In addition, intermittent flooding also helps in reducing the emission from 16% (Pramono et al., 2022) to 37%, including compost treatment (Hwang et al., 2017) of CH₄ emission from paddy fields. Therefore, a combination of both the remedial measures would help in reducing 40 to 45% of the total emission of CH₄ from the paddy fields.

Conclusion

From the observations made from the literature cited, it can be concluded that the application of green manure and non-composted animal manure does not help in reducing the emission of CH₄ although the yield of rice may be enhanced. The application of compost or chemical fertilisers alone is also not sufficient for maintaining a balance between CH₄ emission and crop production. A combination of tested locally available composts/vermicompost and NPK fertilisers is necessary in order to reduce the emission of CH₄ from paddy fields without compromising the yield and soil quality. In addition, intermittent wetting and

drying instead of continuous irrigation also help in reducing the CH₄ emission. A combination of both process would help in reducing 40 to 45% of the total CH₄ emission from paddy fields. However, the process of intermittent irrigation will be a difficult step for the farmers to take up, as they are adapted to the age-old practice of continuous flooding. It will also need extra expenditure and labour which they may not be able to bear. Therefore, steps can be taken up by lawmakers to minimise the cost.

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