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Greenhouse gas emissions from paddy fields in peninsular South India

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Abstract

The six southern states of India ─ Andhra Pradesh, Tamil Nadu, Karnataka, Kerala, Telangana, and Puducherry ─ are among the major rice producing regions of India. These states also have predominantly humid tropical climate which is conducive to anaerobic digestion. The combination of the two aspects makes it necessary to learn about the greenhouse gas (GHG) emissions that occur in those regions. Only such an information can help in identifying the causative factors and correcting them. Given that reducing anthropogenic GHG emissions is the topmost global priority, this exercise is of utmost importance. In view of this, an extensive state-of-the-art survey was conducted of the reports on GHG emissions from paddy fields of peninsular India. The details are presented.

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1. Introduction

India is the second largest producer of rice in the world, a close second to China who is the leader in this respect. Of the present Indian rice production of about 95 million metric tonnes per annum, about 18% comes from India's six southern states ─ Tamil Nadu, Andhra Pradesh, Karnataka, Kerala, Telangana, and Puducherry (Government of India 2015). These states of peninsular India are characterized by the prevalence of humid tropical weather, with average ambient day time temperatures at 30ºC or higher most of the time in most regions as also absence of sharp fall in the night time temperatures. These conditions are conducive for anaerobic digestion of which optimum temperature in the mesophilic range is 35ºC.

In view of the fact that about 8 million hectares of the total area of these states is under rice cultivation, and considering that the temperatures prevailing most of the time there are conductive to anaerobic digestion it is important to know what is the extent of generation of global warming gases (GWG) methane (CH_4) and nitrous oxide (N_2O) in these paddy fields. Only by assessing the GHG emission and identifying the factors that promote them can practices be evolved to reduce the emissions. Given that as much as5 - 19% of all anthropogenic CH_4 emission is attributed to paddy cultivation (Wang *et al.*, 2017), control of rice–related GWG is a global priority.

The present paper is a state-of-the-art review of all the studies reported on paddy field GWG emissions in the six Southern states of India.

2. Methodology

Very extensive search with multiple keywords was made at the *Science Direct*, *Web of Science* and *Google* repositories for material on the subject of the review. As it threw up only 6 reports, further probing was done by seeing cross-references in various reviews earlier published on GHG emissions from Paddy fields and by searching with more key words.

3. The findings

3.1 General

The most significant finding is the very surprising and shocking lack of reports on the rice-related GWG emissions in peninsular India. The paucity is particularly unfortunate considering that rice is the most extensively cultivated of plants in these regions. The search revealed that as few as six studies have been reported so far and only 4 of them are based on actual measurements of CH_4 emissions. Further, there is not a single report which addresses the issue of N_2O emissions. Considering that N_2O has 300 times higher global warming potential than $CO_2$and also the fact that chemical fertilizers are known to cause N_2O emissions (Das and Adhya 2014; Bhattacharyya *et al.*, 2012; Bhattacharyya *et al.*, 2013; Gogoi and Baruah 2012) this summary lack of information on N_2O is most shocking. Unfortunately, at the national level, too, studies on N_2O emissions are very few so far (Luithui*et al.*, 2018).

3.2 Experimentally determined CH_4 emissions

The first-ever study on methane emissions in South India was carried out by Lal*et al.*, (1993) during 1991-92 in Thanjavur which is one of the major rice growing areas in Tamil Nadu. Lal *et al.*, (1993) employed a sampling strategy as shown in Figure 1. After analyzing methane concentration as a function of time they constructed regression lines between the two variables and calculated the methane flux using the equation.

$$\text{Flux (mg } m^{-2}h^{-1}) = \frac{M.n\,(air).V}{N.A}\frac{dr}{dt} \times 10^7$$

Where
M=molecular weight of CH_4,(g);
N=Avogadro's number (molecules/g-mole);

n(air) = air density (mol cm^{-3});
V= chamber volume (cm^3);
A = surface area of the chamber (cm^2);
dr/dt=rate of change of CH^4 mixing ratio (h^{-1}).

The authors found that methane flux varied greatly with the age of the plants. Besides the plant's physiology, they attributed the variability to the water levels, stagnation period of water, soil temperature, etc. The flux value increased from a low of the order of 1-4 mg (CH_4) m^{-2} h^{-1}, for young plants of 30-45 days, to a maximum for the age group of 50-80 days. Most of these fell in the range of 15-25 mg(CH_4) m^{-2} h^{-1}. After the plants were about 80-90 days old, methane flux started decreasing.

Additionally Lal *et al.*, (1993) made observations on the control soils ─ flooded or dry. It showed very low flux values, close to zero, for the flooded soil without paddy. As for dry soil, there was even a negative slope indicating it to be a sink rather than source for methane.

Lal *et al.*, (1993) also noted that the methane flux values measured at Thanjavurwere higher thansome of the other values reported for India (Parashar*et al.*, 1991) which were only 1. 5mg m-^{2}h^{-1} in theDelhi region and 0.1 mg m^{-2} h^{-1} in the Dehradun region. However, the data for Karnal in the Haryana region showed a flux of 27.5 mg m^{-2} h^{-1}. Lal *et al.*, (1993) felt that these differences, if true, could be due to differences in climatic conditions and agricultural practices.They emphasized that more measurements from selected regions of different climatic and agricultural conditions were needed to understand the factors behind the variability in the methane flux.

Despite the abovementioned observations of Lal *et al.*, (1993), no other study was undertaken for 15 years. Then Krupadam*et al.*, (2007) published their findings on methane emission from Godavri estuary as compared to the emissions from nearby paddy fields. They found that values of the maximum methane emission from the estuary occurringduring winter, summer and monsoon seasons were 12.8, 14.8 and 12.1 ppmv, respectively. The average maximum and minimum value observed for the five-estuary sites was 14.8 and 3.67 ppmv, respectively. In contrast much lower methane concentration were noticed in the paddy fields, though they hadseasonal pattern similar to the one exhibited by the estuary. There was no significant difference between rates of CH_4 emissions during the day and during the night. The seasonal trend with reference to estuary samples showed relatively high methane values during winter, which was mainly due to atmospheric stability resulting in low dispersion. Other factors like high moisture content, short day lengths, low solar intensity and low temperature may have been responsible for reducing the photochemical destruction of methane. Paddy fields had much lower methane emissions even though they had similar seasonal and day-night patterns of methane emission as the estuary had. The authors attributed higher methane emission from the estuary to its soils having huge quantity of organic matter coming into the estuary from nearby mangrovesbesides the soil chemistry: Presence of high available Fe and favourable soil redox potential (−120 mV)may have made the soil conducive for higher methane emissions.

Another five years passed when the third report on methane emissions from peninsular rice fields appeared, that of Lakshmanan*et al.*, (2012). The study they reported was carried out at Trichy, during the 2010–2011 Rabi season, employing the

TNAU(R)TRY 1 rice variety with different fertilizer applications: T_1Control, T_2Blue Green Algae, T_3Azolla, T_4Farm Yard Manure, T_5Green Leaf Manure, T_6Blue Green Algae+Azolla, T_7Farm Yard Manure + Green Leaf Manure, T_8 Blue Green Algae + Azolla + Farm Yard Manure + Green Leaf Manure. Basically, the field experiments were conducted by the authors to study the influence of temperature, air, soil, and water under different organic amendments on methane flux in rice cultivation. As redox potential, soil temperature and dissolved oxygen in the flooded rice soil are major factors influencing the methane flux; their concentrations were monitored by Lakshmanan*et al.,* (2012)in all treatments throughout the growth stages to obtain correlation between temperature/ redox/ dissolved oxygen and methane flux. Minimizing CH_4 flux in rice cultivation being an important climate change mitigation strategy, the influence of photosynthetic systems such as blue green algae (BGA) and Azolla on soil redox, dissolved oxygen and CH_4 emission was studied. As BGA and Azolla supply nitrogen and other growth regulators to the rice crop besides CH_4 emission reduction, their role in enhancing the yield in rice cultivation was also attempted to be quantified.

It was seen that the plots applied with farm yard manure and green leaf manure separately (T4 and T5) and also in combination (T7) recorded higher soil andwater temperature,possibly due to the decomposition oforganics and mineralization processes which might haveenhanced the soil temperature in these plots.The plots treated with BGA and *Azolla*registeredlower soil and water temperature and the sametrend was also noticed during all growth stages. The BGA and *Azolla*tended to form a matover the water surface which reduced thepenetration of solar radiation. Moreover BGA and*Azolla*being photosynthetic systems releasedoxygen into soil– water interface that reducedthe water and soil temperature in theexperimental plots. The consequent aerobic conditions discouraged methane production.

All in all it was seen that the combined application of organics and blue green algae not only led to higher yield of rice, but also resulted in lesser methane emission in paddy cultivation than the application of organics alone. Bio fertilization of paddy fields with blue green algae and *Azolla*appeared to be a potential climate change mitigation strategy due to their role in reducing methane emission, besides yield enhancement by nitrogen fixation.

The last report on the subject of this review has been published by Rajkishore*et al.,* (2013). They conducted field experiments at the Department of Environmental Sciences,Tamil Nadu Agricultural University, Coimbatore, to compare the methane emissionpatterns associated with paddy cultivation the by the System ofRice Intensification (SRI) and the conventional methods of growing rice, during summer and kharif seasons in2011. The studies were prompted by the fact that SRI is being increasingly adapted in many Asian countries (Uphoff 2012) due to its ability to increase rice yield at lesser water inputs. In Tamil Nadu, the use of SRI had increased from just a few hundred hectares in 2003-2004 to 750,000 ha by 2008-09 (Uphoff and Mishra 2009). It has been further increasedto over 1,001,000 ha by now (Governmentof Tamil Nadu, 2012). But even though the significance of SRI for raising rice yield and reducing water requirements hasbeen repeatedly demonstrated, attemptsto assess the pattern and the drivingforces of methane emission with SRI have been very few (Jain *et al.,* 2013; Suryavanshi*et al.*, 2013).

Rajkishore*et al.,* (2013) monitored methane emission patterns at four main stagesof plant growth: active tillering, panicle initiation, flowering, and maturity. They also recorded temporal changes in methane emissions in relation to soil-aerating cono-weeding, andmeasured changes in the relevant soil biota.

It was found that methane emissions increased progressively with the advance of crop growth untilflowering and then declined thereafter. The quantum of methane emission was consistentlyhigher under conventional crop management compared to the SRI method of cultivation, to the extent of 27.8-42.6% during summer season, and 33.0-43.1% in kharif season. The cumulative methaneemissions for the entire cropping season were also considerably higher inthe conventional cultivation (44.6 and 55.5 kg ha^{-1}) as compared to the SRI (31.8 and 37.7 kg ha^{-1}) in the summer and kharif seasons,respectively. Overall, under SRI total methane emissions werereduced by 29 and 32% during the summer and kharif seasons, respectively.

It was further deducedby Rajkishore*et al.*, (2013) that the practice of cono-weeding employed with SRIby itself contributed 19 to 63% of the reduction in methane emissions achieved under the SRI. The populationsof methanogens were significantly lower under SRI than in conventional crop management regardless of the plant growth stage, while the reverse was true with the microorganisms that consumed methane. Overall, the data suggested that the SRI led to reducing of methane emissions, which, in turn, was significantly associated with the practices of cono-weeding and intermittent wetting and drying of paddies that go with SRI.

3.3 Other relevant studies

The other two studies related to the theme of this review are not based on methane emission measurements but are broad theoretical estimates of methane emissions, made using algorithms which correlate remotely sensed temperature profiles with methane emissions (Matthew *et al.*, 2013, 2014). They seek to inform that the estimated methane emissions from flooded paddy fields in Andhra Pradesh have increased in 2013 from their 2001 estimates.

4. Summary and conclusion

An extensive global study of the state-of-the-art of greenhouse gas (GHG) emissions from paddy fields in peninsular South India was carried out. It revealed a shocking paucity of information on the subject. Only four studies are available on measurement of GHGs but all are confined to methane. Not a single study on the other GHG associated with paddy cultivation ─ viz nitrous oxide ─ is available. This general lack of information is particularly surprising in view of the presence of very many institutions and centers of excellence in this region as also the fact that there is more area under rice cultivation in this region than for any other crop. The four available reports are too few to permit any generalization but they do provide useful pointers on the factors that contribute to methane emissions in the region and how practices such as the System of Rice Intensification (SRI) can help in the reduction of the emissions.

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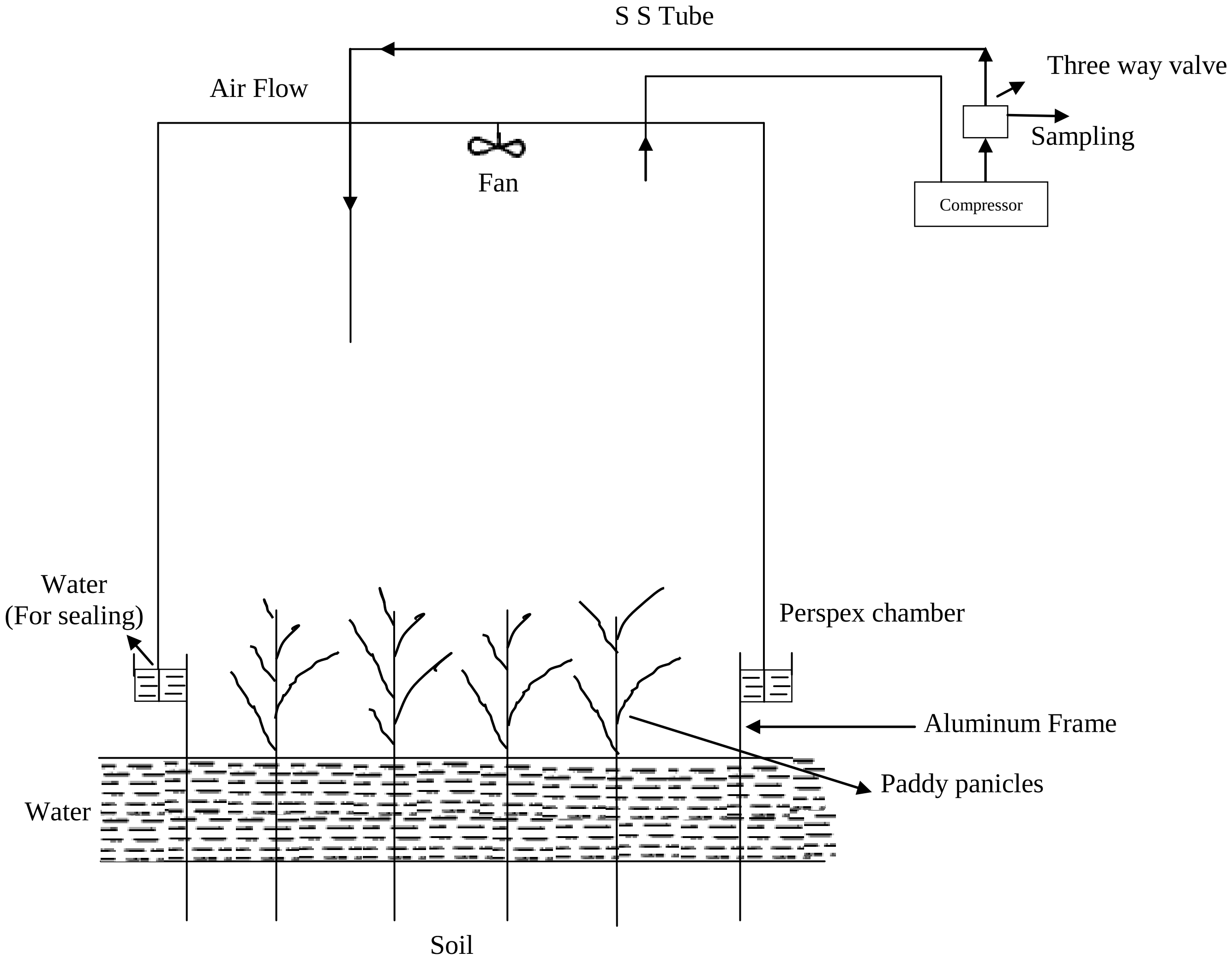

Figure 1: The experimental set up of Lal *et al.*, (1993)