

Mitigation measures

for GHG emissions from paddy soils in South Asia

**Somasundaram Jayaraman*, Brijesh Yadav, Nishant K Sinha,
Ashok K Patra and Ram C Dalal**

ICAR-Indian Institute of Soil Science, Nabibagh, Bhopal, Madhya Pradesh 462 038

Agricultural soils act as a major sink and source of greenhouse gases (GHGs) such as methane (CH₄), nitrous oxide (N₂O), and carbon dioxide (CO₂). In South Asia, paddy fields have long been a source of concern for scientists, as they produce long-lasting GHGs, primarily CH₄ and N₂O. Changing conventional crop management practices to good agricultural practices with appropriate resource conservation technologies could have a big influence on lowering GHG emissions from paddy fields. Thus, understanding the mechanisms of CH₄ and N₂O production, and emissions from paddy soils, as well as the factors that limit emissions, are critical for developing mitigation measures to reduce GHG emissions. In this article, existing data were used to create a comprehensive analysis of appropriate rice crop management strategies for reducing GHG emissions. The GHG emissions can be reduced through the adoption of best management practices, precision farming, improved soil and agronomic practices, and resource conservation technologies.

Keywords: Greenhouse gas emission, Methane, Nitrous oxide, Paddy soils

THE rice-wheat cropping system (RWCS) is the dominant agricultural production system in South Asia, and covers about 13.5 mha (million hectares), mostly in India, Pakistan, Bangladesh and Nepal. In South Asia (SA), achieving food and nutritional security by increasing crop productivity and reducing inter-annual crop yield variations have become a formidable challenge. Moreover, there is clear evidence of climate change, having a negative impact on crop productivity in this area. The existing levels of greenhouse gas (GHG) emissions must be decreased significantly in order to maintain temperature rise below 2°C. Agriculture, forestry, and other land use sectors emit around a quarter of all anthropogenic GHG emissions (9–12 Gt CO₂eq/yr), primarily from deforestation and agricultural practices. This SA region has the highest proportion of methane emissions throughout Asia.

Agriculture is more likely to increase GHG emissions in SA due to higher food requirement to meet the growing population demand. Methane (CH₄) emissions are primarily generated by the livestock and paddy production, while nitrous oxide (N₂O) emissions are primarily released by the application of manures and fertilizers. The emissions of GHG from rice cultivation have risen over time in SA. The CO₂eq has increased from 103.35 teragrams (Tg) in 1961 to 137.72 teragrams in 2020. Further, this region emits nearly 4900 gigagrams (Gg) CH₄/yr from rice cultivation itself, making it the world's third highest source of methane from rice cultivation.

In India, puddled rice contributes about 24% of total agricultural CH₄ emissions [3.37 MT (metric tonnes)/yr], while nitrogenous fertilizer application in rice, wheat, and other crops emits about 0.14 MT N₂O/yr.

However, in direct seeded rice, CH₄ and N₂O emissions are 0.1 and 1.2 tonnes CO₂eq/ha, respectively, and in puddled transplanting system, the respective emissions are 0.6 and 0.4 tonnes CO₂eq/ha. Rice and wheat crops have carbon footprints of 8.80 ± 5.71 and 4.18 ± 1.13 tonnes CO₂eq/ha, respectively, while they have 1.20 ± 0.70 and 0.83 ± 0.23 tonnes CO₂eq/tonne, respectively, on a tonne of grain basis. Rice had a Global Warming Potential (GWP) of 3401 kg CO₂eq/ha, while wheat had a GWP of 3968 kg CO₂eq/ha. Apart from these, about 2.5 million farmers burn 23 MT of rice stubble every year to prepare fields for wheat sowing, causing air pollution that affects millions of people. It is estimated that crop burning produces annual emissions of CO₂ (379 Tg, 1 Tg = 10¹² g), CO (23 Tg), CH₄ (0.68 Tg), NO_x (0.96 Tg), and SO₂ (0.10 Tg) through crop burning.

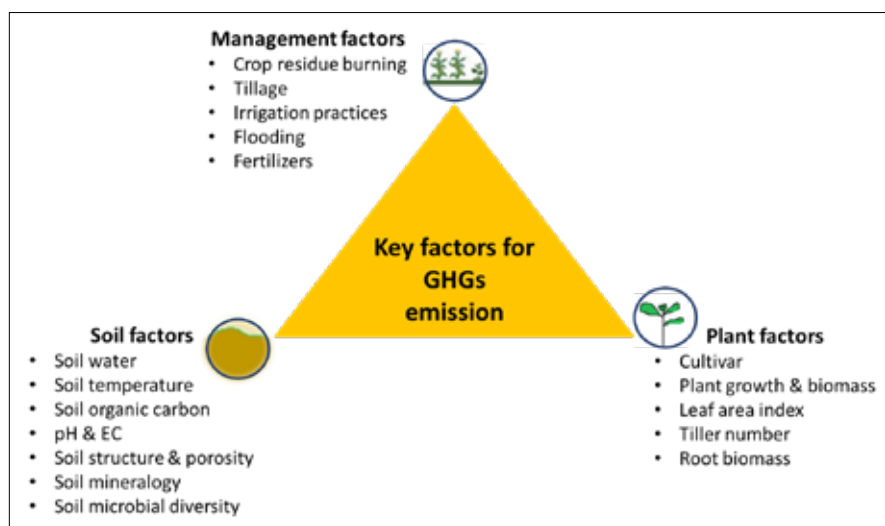
Process of GHG production

The conventional farming practices such as intensive tillage, large scale residue burning and frequent irrigation consume a lot of energy and emit significant quantities of $\text{CO}_{2\text{eq}}$ into the atmosphere. In paddy soils, CH_4 is produced by methanogens under anaerobic conditions, from the utilization of organic carbon through the process of methanogenesis. After the production of CH_4 , it is transported from soil vertically to the atmosphere through three main pathways namely diffusion through water-air and soil-water interfaces; release through ebullition; and transport through plant roots, aerenchyma and cortex, and subsequent release through plant micropores. In rice fields, nitrification (oxidation of NH_4^+ to NO_3^-) and denitrification (reduction of NO_3^- to N_2O) in soil are the main processes for the production of N_2O . The key factors that affect N_2O emissions from paddy soils are nitrogen management practices and soil water conditions.

Factors affecting GHGs emission

The GHG emissions in paddy soil are largely affected by soil, crop and nitrogen fertilizer management, and plant factors. Soil properties have significant influence on the release and transformation of GHGs as affected by climate and cropping systems.

Soil factors: Soil porosity, soil temperature, SOM, soil mineralogy,



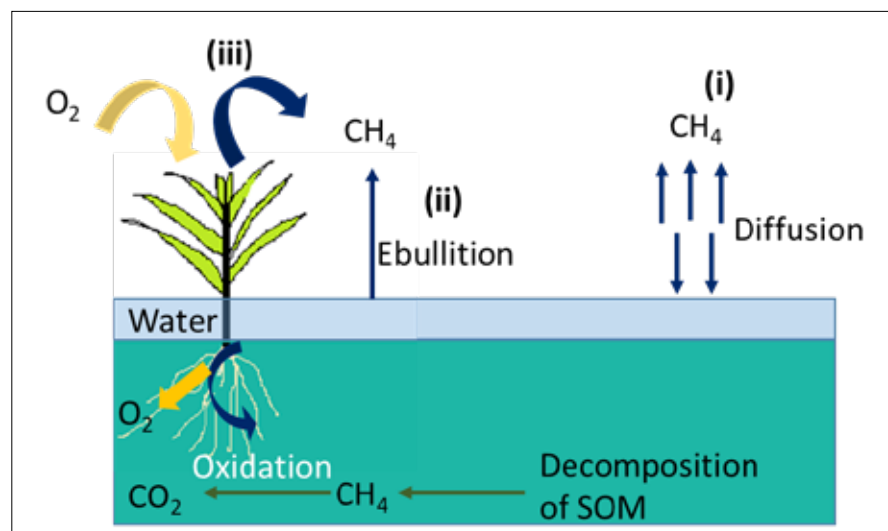
Factors affecting GHGs emission from the rice crop

pH and soil N apparently control emissions of GHGs from soil. Due to high infiltration rates, CH_4 emissions are lower in sandy and sandy loam soils as compared to clay soils. Because, coarse-textured soils have higher porosity than clay soils, hence flooded water cannot be retained for a longer period to create anaerobic conditions. With a threshold level of 150 mV, soil redox potential (Eh) is known to primarily control the rate of CH_4 production in paddy soils.

Crop and nitrogen fertilizer management factors: Crop management factors such as residue burning, tillage and irrigation practices, along with faulty fertilizer practices have greater influence on GHGs emission. Excessive use of synthetic fertilizers increased GHGs emission after the green revolution in agriculture. The amount of CH_4 released is significantly affected

by the quality, quantity, method and timing of fertilizer application. The basic requirement for the sustained release of CH_4 is standing irrigation water or waterlogged soil. Depending on water management, the fluctuation in CH_4 varies between the submerged field and the drained field. As a result, irrigated rice has a higher potential for CH_4 emissions than rain-fed rice. Moreover, tillage disturbs the soil structure and aggregation resulting in prolonged water logging and thus, enhances CH_4 emission from the soil.

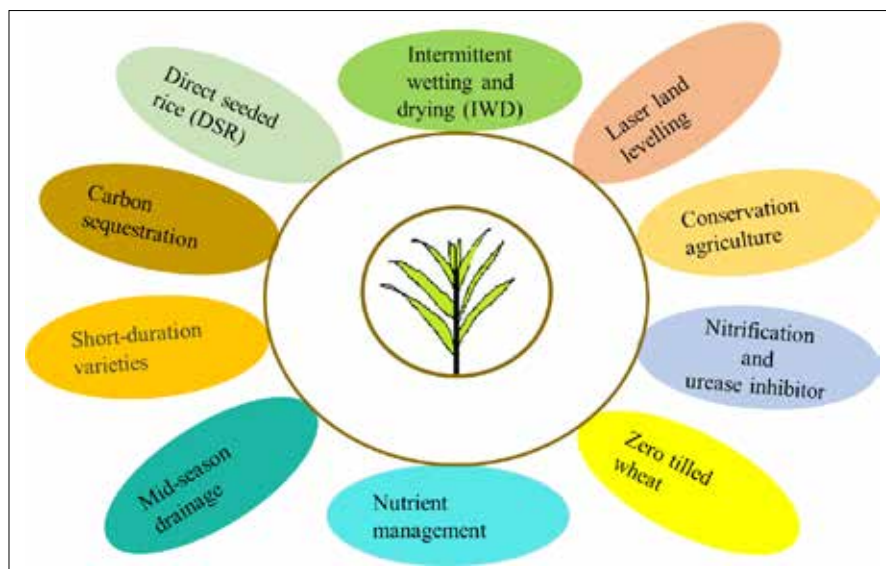
Plant factors: Rice varieties influence CH_4 emissions from flooded paddy soil. The morphological features of rice cultivars, such as root growth, root exudates, leaf area index, biomass, multiple tillers, and rice duration, all play a role in the variation of CH_4 emissions.



Production of methane in rice field (Source: Van der Gon and Neue 1996)

Strategies to reduce GHGs emissions

The GHG emissions can be reduced through adoption of precision farming, improved agronomic and nitrogen management practices, and resource conservation technologies. Many strategies for reducing GHG emissions from rice-wheat cropping system have been identified. Some improved technologies are direct seeded rice; intermittent wetting and drying; and mid-season drainage; conservation agriculture; zero tilled wheat; laser land levelling; and use of nitrification and urease inhibitors for reducing GHG emissions.



Strategies to reduce GHGs emission from rice-wheat fields

Other technologies such as carbon sequestration in soil through brown manuring, reduced tillage, mulching and soil biodiversity improvement, can play an important role in mitigating climate change. Some of the mitigation practices are:

Mid-season drainage: Draining paddy fields in the middle of the rice growing season is a better water management practice than continuous floods irrigation. To avoid rank growth and to lower the number of ineffective tillers, a short-term drainage (5–20 days) is usually performed before the maximum tiller number stage, and the duration is controlled by regionally established conventional methods. Drainage in the middle of the growing season improves soil oxidative conditions and ultimately reduces CH_4 emissions.

Alternate wetting and drying: The periodic drying and reflooding of the paddy field is known as alternate wetting and drying. The time interval between dry and wet conditions is too short to support the transition from aerobic to anaerobic soil conditions, in contrast to mid-season drainage. The use of alternate wetting and drying reduces CH_4 emissions significantly, however N_2O emissions from this system vary widely. Water drainage and the resulting aerobic soil conditions allow CH_4 to be oxidised rather than emitted.

Direct seeded rice: Traditional

transplanted puddled rice is a major source of GHG emissions, but direct-seeded rice (DSR) has been proposed as a viable alternative to transplanted puddled rice, with the ability to reduce GHGs emissions. When compared to transplanting rice seedlings, direct seeded rice methods cut CH_4 emissions by 16–54%.

Nutrient management: Nutrient application in a balanced dose improves crop yield while simultaneously lowering GHG emissions. To reduce GHGs emission, it is required to apply the 4R principles of nutrient application, i.e. right time, right rate, right place and right source. Both CH_4 and N_2O emissions from paddy fields can be reduced using nitrification inhibitors or slow-release nitrogen fertilizers. Nitrification inhibitors limit N_2O emissions directly by inhibiting the process of nitrification and indirectly by lowering the nitrate availability for denitrification. Similarly, applying urease inhibitors, dicyandiamide, and hydroquinol, with urea and nitrification inhibitors, 3,4-dimethyl pyrazole phosphate and nitrpyrine with either urea or ammoniacal fertilizers to the soil have been proven to lower CH_4 emissions considerably. The choice of fertilizer is crucial when it comes to reducing GHG emissions. Ammonium sulphate is a sulfate-containing nitrogen fertilizer that reduces CH_4

emissions by 25–36%. Similarly, urea combined with phosphor-gypsum reduces CH_4 emissions by up to 70%. In addition, potassium application can significantly reduce CH_4 emissions from flooded paddy soils and can be applied as a mitigation alternative, particularly in potassium-deficient soils.

Rice cultivars with low methane emission potential: Selection of suitable cultivars has long been recognised as a viable technique for reducing GHG emissions in paddy soils. Rice varieties with small root systems, strong root oxidant activity, and more productive tillers release less CH_4 as compared to variety with larger root systems. With a threshold level of 150 mV, soil redox potential (Eh) is known to primarily regulate the CH_4 production in paddy soils. Over the course of the rice growing season, root respiration and exudation, above ground biomass, and the stage of rice plant development have been shown to influence soil Eh. Variations in these parameters, as well as dynamic changes in soil Eh, are strongly linked to CH_4 emission from paddy fields.

Improved tillage practices: During tillage operations for rice field preparation, CH_4 emissions are extremely high. Conventional tillage practices increase emissions by breaking down soil aggregates and releasing protected organic carbon. However, soil carbon loss can be reduced by using conservation agricultural techniques like zero tillage and minimum tillage, which result in lower GHG emissions. The usage of a laser land leveller instead of a conventional land leveller decreases GHG emissions by reducing water pumping time, cultivating time, and fertilizer use.

Crop residues management: Crop residue management decisions should be based on productivity, profit, and environmental impact. Instead of burning rice straw in the field, appropriate usage of rice straw can help to reduce GHG emissions. Rice straw can be used as *in situ* incorporation, mulching, composting, bioenergy production and as raw material in mushroom

farming. The incorporation of rice stubble into the soil improves physical, chemical, and biological soil properties.

Application of methanotrophs: In the paddy field, methanogen microbes are responsible for the production of CH₄. In this context, attempts are being made to inoculate CH₄ oxidizing microorganisms, such as methanotrophs, NC10 phylum, and verrucomicrobia, which are capable of utilising CH₄ as a carbon source and reducing atmospheric CH₄ emissions. These methanotrophs are alternative measure as bioremediation agents in paddy fields and are regarded as an essential global CH₄ sink.

Way forward

Despite the fact that there are numerous climate change adaptation and mitigation strategies available for agriculture in SA, many farmers still use traditional farming practices and eventually result in higher GHGs emission. Farmers need to be provided incentives for adoption of GHG reduction practices which can also encourage others for managing their fields. Therefore, formulating appropriate policies that support food security and sustainable development goals

(SDGs) are essential with better understanding of the socio-political environment and farmers' behaviour in connection to the adoption of these cost-beneficial GHG mitigation methods. Scaling up the adoption of climate-risk adaptation and mitigating techniques at the farm level is also significantly hampered by the absence of defined policies, guidelines, and coordination between policies at various levels. Institutional policies are therefore needed to address local problems and link global, regional, and local climate change issues. Moreover, future studies should examine the trade-offs between GHG emissions and food security in various agricultural production systems, in addition to emission-reducing approach and strategies.

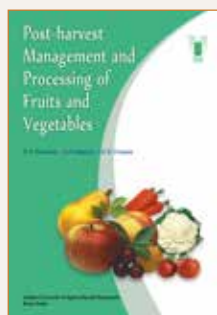
SUMMARY

In South Asia, puddled transplanted rice followed by intensively tilled wheat (R-W) is the most dominant cropping system and the lifeline for billions of people. This cropping system requires high amounts of water, nutrients and energy which increases production costs and GHGs emission. Paddy fields are considered as one of the major sources of anthropogenic

GHGs emission, particularly methane (CH₄) and nitrous oxide (N₂O). Therefore, to sustain agricultural production and ecosystem services adaptation-led mitigation actions are required. It is widely recognised that a number of factors including soil properties, plant factors, and farm management practices affect the emissions of these GHGs from paddy fields. Various soil properties such as soil porosity, soil mineralogy, soil organic carbon, and soil hydro-thermal regimes significantly control GHGs emission. Similarly, different agronomic and farm management practices such as excessive fertilizer application, faulty water management practices, crop residue burning have significant impact on GHG emissions. The GHG emissions can be reduced through the adoption of best management practices such as direct seeded rice, intermittent wetting and drying, mid-season drainage, conservation agriculture, zero tilled wheat, laser land levelling, use of nitrification and urease inhibitors, balanced fertilizer application and precision farming.

*Corresponding author's e-mail: somajayaraman@gmail.com

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Post-harvest management technology offers promising option for increasing production of vegetables and fruits quantity-wise and also in maintaining quality of the products. It involves all the activities that occur after production or harvesting of commodities, including procurement, removal of field heat, sorting, grading, packaging, storage, transportation, primary and secondary processing and marketing of agricultural products from farm-gate to distributors. This book is an effort to document vast available knowledge on the various aspects of post-harvest management and processing, and it will prove worthy for teachers, students and extension workers for understanding post-harvest management and processing of fruits and vegetables. It has 16 chapters covering storage, packaging, advanced preservation technology and value-addition of fruits and vegetables.

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