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*Review Article*

# Integrated nutrient management - promising way to reduce carbon dioxide and methane emission in flooded rice ecosystem: A review

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**Abstract**
Climate change is an inevitable ruling issue caused by the increasing concentration of greenhouse gases (GHG's) in the atmosphere worldwide. It will have a considerable impact on agriculture and its related fields like live stocks and fisheries. In India, the main sectors contributing to these emissions are industry, agriculture and waste, with a total emission of 334 MT CO2 eq. Besides, the major sources in agriculture are enteric fermentation (63.4%), rice cultivation (20.9%), agricultural soils (13.0%), manure management (2.4%) and on-field burning is the crop residue (2.0%). Thus, the crop productivity sector (rice cultivation, soil and field burning of crop residues) contributes 35.9% to the total emission from agriculture. Therefore, reducing GHG emissions and enhancing the C sequestration in soil and biomass has become challenging. However, the total GHG's emission from all sectors of the country has decreased from 33% in 1970 to 18% in 2010. Cutting off GHGs emission from agriculture can be achieved by sequestering C and reducing methane emissions(CH4) and carbon dioxide(CO2) through various soil and crop management strategies. Integrated nutrient management (INM) practice ensures the Soil –plant –atmospheric continuum (SPAC) in a promising way, reducing the GHGs emission by sequestering more carbon to soil than emissions. A studious prominent INM solution can be identified to develop a mitigation strategy that helps in climate change adaptation and sustains soil health through soil carbon sequestration.

**Keywords**: $CO_2$, $CH_4$, Carbon sequestration, Climate change, Integrated nutrition management.

## INTRODUCTION

Global warming is the most predominant environmental issue across the world. Among the various sources of GHG's agriculture is considered a major contributor, primarily through methane, carbon dioxide, and nitrous oxide. In addition to that, biogenic sources contribute to over 70% of the global CH4 emissions and paddy fields, as major anthropogenic sources of CH4 emissions account for 5-19% of the global anthropogenic CH4 budget and climate change (Wang *et al.,* 2015). According to a report of Indian Network for Climate Change Assessment, the net emission of GHG's from India was 1728 million tons (MT) of CO2 eq. in the year 2007. The main sectors contributing to these emissions are industry, agriculture and waste, with a total emission of 334 MT CO2 eq. The major sources in agriculture are enteric fermentation (63.4%), rice cultivation

(20.9%), agricultural soils (13.0%), manure management (2.4%) and on-field burning is the crop residue (2.0%).

Various agricultural activities such as land clearing, cultivation of crops, irrigation, animal husbandry, fisheries and aquaculture have a significant impact on the emission of GHGs (IPCC, 2014). Hence, it is, therefore, pertinent to develop technologies to reduce CH4 and CO2 emission from the cereal-based crop production system. Among the various strategies, manure management contributes a considerable share in sustaining soil fertility and reducing GHG's emission. Pertaining to nutrient management, the addition of nutrients throughinorganic fertilizers is inevitable for any crop grown in the conventional cropping method. However, in recent years there has been serious concern about the long term adverse effects of continuous and indiscriminate use of inorganic fertilizers on the deterioration of soil structure, soil health and environmental pollution (Singh, 2000).

The utilization of indigenous organic sources like farmyard manure (FYM), other forms of compost and green manures may serve as alternatives or supplements to chemical fertilizers and increase the productivity of the rice-based cropping system all parts of the country (Manivannan and Sriramachandrasekharan, 2016). Soil fertility management is more important for higher crop production, maintenance of fertility and sustainable crop production.

Integrated nutrient management (INM) practices involving organic and inorganic sources based on their availability and cost-effectiveness and the judicious combination of these two sources have been mutually reinforced. The efficiency of both sources results in higher productivity and soil fertility. Besides, the application of organic manures alone during anoxic condition eventually increased the GHGs emission, whereas, combined with inorganic fertilizers enhanced the soil organic carbon content rather than the emission. An in-depth understanding of the trends in GHG emissions, their regardless drivers, and the relation between the two is essential for comprehending the need for mitigation. Hence, the present review aspires to reveal the effect of INM on CO2 and CH4 fluxes and yield potential in rice-based production system. Simultaneously, the objectives of this paper are to reveal the emission of GHGs from Indian agriculture and analyze the appropriate combination of INM practice to sequester more soil carbon rather than the GHGs emission to sustain the soil health and mitigating climate change with increased yield potential of crops.

**Organic manures on $CO_2$ emission in rice production**

Agricultural management practices that include changing the soil environment (C/N ratio of substances, soil temperature, and soil moisture) affect soil CO2 flux. These soil characteristics affect the microbial activity in the soil and its decomposition that transforms plant-derived C into CO2 and soil organic matter SOM (Franzluebbers *et al.,* 1995). Though the soil carbon mineralization and $CO_2$ evolution have been paid great attention for their important effects on global carbon cycle and terrestrial ecosystem functioning (IPCC, 2001; Valentini *et al*., 2000; Jenkinson *et al*., 1991). The maximum CO2 flux recorded in organic amendment can be attributed to the combined effects of available C substrate, soil temperature, moisture regimes over the non- amended treatment reported by (Smith *et al*., 2003), and higher microbial activity (Rochette *et al.,* 2004. Relatively some research studies concluded that the cumulative carbon dioxide flux was higher in the treatments received cow dung (CD) application (854 mg $kg^{-1}$) followed by cow dung + rice straw (RS) (828 mg $kg^{-1}$) and cow dung + lime (780 mg $kg^{-1}$) application (Naher *et al.,* 2004). similarly, the animal manure is act as a readily-available source of C and its application had a positive influence on microbial activity that can increase CO2 emissions in annual cropping system (Rochette *et al.,* 2004) and also, a higher value of CO2 flux (706 g CO2 Cm-2) recorded through the application of organic manure–N compares to NH4NO3-N (488 g CO2 $Cm^{-2}$) in switchgrass (Lee *et al.,* 2007). In contrast, the application of organic substances or manure at high rates in the fields caused the deposition of soil and organic substances, which reacted with soil particles to form complex compounds that were hardly decomposed into carbon dioxide (Suwannarit, 2008). Incorporating rice residues for the next season, cropping is an important practice followed by the farmers in the low land ecosystem. Rice residues were categorized as low-quality organic material since they comprise a high content of carbon (367-423 g $kg^{-1}$), and low content of nitrogen (4.7-8.5 g $kg^{-1}$) and lignin (19 - 45 g $kg^{-1}$). Wherever it is incorporated into soils with optimal conditions, it rapidly decomposes and leads to an increase in CO2 evolution (Samahadthai *et al*., 2010; Puttas *et al.*, 2011). Whereas the incorporation of maize straw into soil along with nitrogen and sufficient moisture levels significantly affected the rates and cumulative CO2-C evolution. It brought roughly a 50% increase in collective CO2-C production compared to control (Abro *et al.,* 2011). Similarly, in research studies, the results of Koul *et al.* (2011) indicated that the conventional land use system recorded lesser value of SOC content due to the minimum amount of residue addition to the soil than extent type of vegetative cover on the land. The application of organic and inorganic fertilizers highly influence soil $CO_2$ and $CH_4$ emissions (Nyamadzawo *et al.,* 2014).In addition to that application of organic fertilizers can enhance microbial decomposition activities and root respiration, leading to the increase of the $CO_2$ emission of soil (Qiu *et al*., 2015; Li *et al.,* 2019). Addition of oil cake fertilizer significantly increased soil MBC content and $CO_2$ emissions, especially single cake fertilizer alone nourished treatments showed the highest emissions (Lin *et al.,* 2021*).*

**Organic manures on $CH_4$ emission in rice production**

Agriculture contributed globally over 11% of the total GHG's emission. Indian agricultural sector, including crop and animal husbandry, emitted 418 Mt of CO2 eq. Enteric fermentation, i.e., emission from ruminant animals, contributed the highest (56%) amount of the emission from this sector, followed by agricultural soil (23%) and rice fields (18%) (Fig. 1a). Burning of crop residues in the field contributed 2% and manure management contributed 1% of the emission. Over the years, several estimates of methane emission from Indian rice fields have been made. In recent years, Indian Agricultural Research Institute, New Delhi, in collaboration with other ICAR and CSIR Institutes, has rationalized the earlier estimate of 37.5 Mt to 3.3 Mt (Fig.1b) (Pathak *et al*., 2014). Among the various rice ecosystems, the highest emission was from the irrigated continuously flooded rice (34%), followed by rainfed flood-prone rice and irrigated single aeration (18%) (Bhatia *et al.*, 2012;2013).

As far as soil concern, good–oxidized soil has a redox potential range up to + 400 mV to + 700 mV, whereas flooded soil probably reach redox potential values lower than -300 mV (Patrick and Mahapatra, 1968). Relatively some research studies concluded that the application of organic manure hastened the fall in redox potential and enhanced CH4 production and emission (Yang and Chang*,* 1997). Especially, incorporation of rice straw in the soil significantly increased CH4 production by 1.2-7.9 times over that of unamended soil (Majumdar *et al.,* 1999). Adhya*et al*. (1994) noticed that $CH_4$ emissions ranged from 4 to 26 mg of C $m^{-2}$ $h^{-1}$ in a rice paddy especially a higher population of methanogenic bacteria, which is responsible for increased CH4 production as well as plant growth and peaked at rice maturity (Reichardt *et al.,*1997); concurrently intermittent irrigation reduces $CH_4$ emission by 36% compared to a continuous flooding system. The higher amount of methane emission observed from rice fields is estimated to be 3.32 Tg $CH_4$ and each year contributing about 3.4 per cent to the global methane budget due to rice cultivation (2.49 Tg $CH_4$-C) (Xiang and Ng, 1996 and Wassmann and Aulakh, 2000). With respect to hourly emission ranged from 0.65 to 1.12 mg of C $m^{-2}$ $h^{-1}$ (Mitra *et al*. 1999). Besides, the average emission values are approximately 21.4 g of C $m^{-2}$, depending upon plant variety and growth environment. In organic residue-amended plots in which the first peak in CH4 emission (4 mg CH4-C $m^{-2}day^{-1}$) was observed at maximum tillering and second peak at 70 days after transplanting (7 mg CH4-C $m^{-2}day^{-1}$) (Abao *et al.,* 2000). In addition to that, application of *Sesbania*, *Azolla* and compost recorded the CH4 emission of 132, 65 and 68 kg $ha^{-1}$respectively in the wet season (Adhya *et al.,* 2000). The extremely high ebullition due to the high input of organic manure at the beginning of the crop season is evidenced in the modelled plant biomass. Thus, root transport capacity is still low, whilst overall $CH_4$ emissions are attained its maximum (Matthews *et al.*, 2000). Smith *et al*. (2003) found that the application of animal manure is effective in terms of carbon sequestering. However, one unit of methane is equal to 23 units of $CO_2$. However, the methane emissions associated with ruminants may counteract this positive effect. With respect to global climate, methane emissions are negative, but they symbolize energy loss from the farmer point of view. In some of the research results showed that the methane flux was high in exposed soil and it ranged between 0.04 and 0.93 mg $m^{-2}$ $hr^{-1}$whereas, inpuddle field of rice doubled the pace of methane emission and it ranged between 0.07 to 2.06 mg $m^{-2}hr^{-1}$ in plots nourished without organic amendments (Khosa *et al.,* 2010). At the same time, the plots supplied through cow manure @ 12.5 t $ha^{-1}$emitted the maximum amount of methane (4.39 mg $m^{-2}day^{-1}$) followed by the decreased rate of manure 9.38 and 3.13 t $ha^{-1}$attained 3.08 and 1.49 mg $m^{-2}day^{-1}$of CH4 respectively in rice (Sampanpanish, 2012). Among the various organic amended plots *viz.,* humified straw, farmyard manure, green manure and rice straw, humified rice straw plots recorded low-level emission of CH4 than other amended materials (Khosa *et al*., 2012). C release initiation differed from the addition of organic amendments to the soil probably two weeks after application, which purely depends on soil temperature, moisture regimes, and methanogenic bacteria availability. Nungkat *et al.* (2014) disclosed that methane emission due to the application of 10 t organic manure and 2 t Azolla $ha^{-1}$on paddy field ranged from 509.82 to 791.34 kg CH4 $ha^{-1}$. Yuan *et al.* (2014) opined that decomposing rice straw is performing as a substrate of CH4 production and kindles CH4 production from soil organic matter and rice root organic carbon. Organic and inorganic ways of fertilization highly influence the soil CO2 and CH4 emissions (Khan *et al*., 2017). Besides, the addition of straw and green manure can enhance soil methane production potentials and the abundances of methanogens (Zhou *et al*., 2020). However, Hoang *et al*. (2019) found that incorporation burned straw into the field could reduce seasonal cumulative CH4 emission. Besides, a positive correlation noticed between DOC and soil CO2 flux. Apparently, DOC provided energy to methanogens to promote CH4 production (Zhou *et al*., 2020).

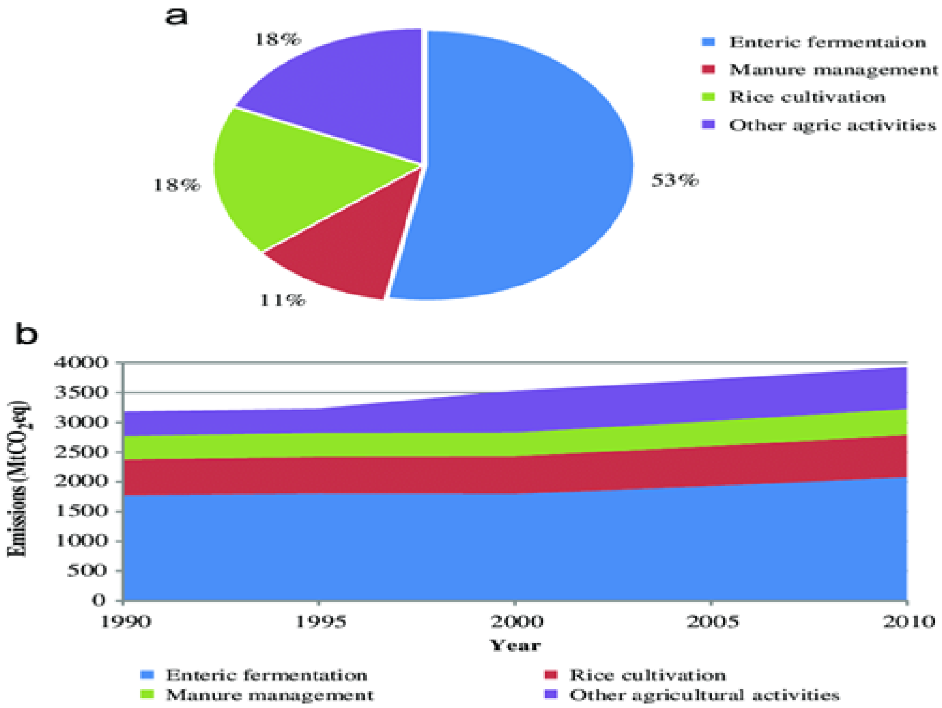


**Fig.1 a.** *Methane emissions from Agriculture; b-Methane emission trend in the Agriculture. Source; Pathak et al., (2010.)*

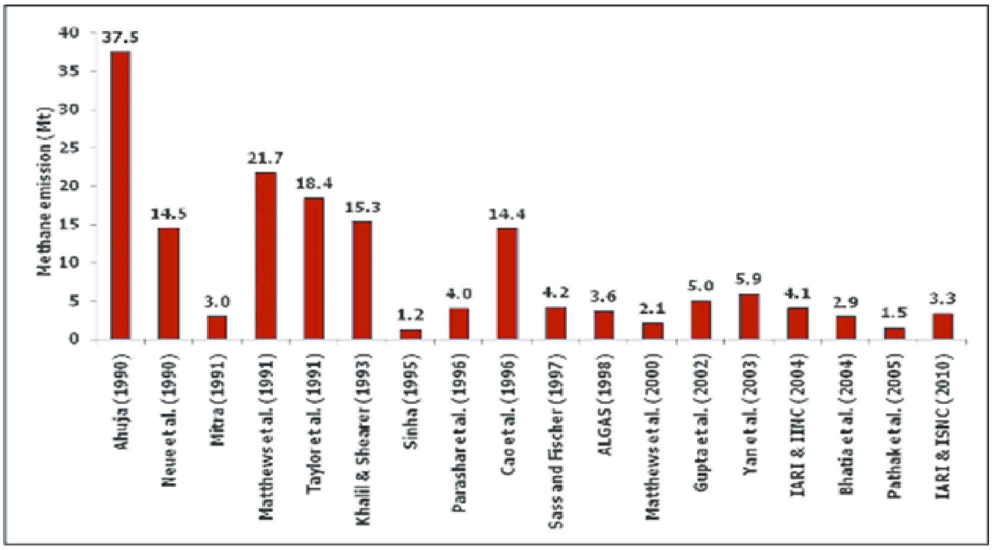


**Fig.1 b**. *Estimates of methane emission from Indian rice fields over the years. IARI 1994, 2000, 2007and 2010 are the values estimated by Indian Agricultural Research Institute, New Delhi for the respective years. Source: Pathak et al. (2014).*

**Organic manures on carbon dynamics in rice production**

The continuous application of organic manures and especially FYM over a period of time increased the organic carbon content of soil (Kenchaiah, 1997). The addition of organic material in the form of municipal solid waste sewage sludge significantly increased the values of biomass carbon, basal respiration biomass C/ total organic C ratio and metabolic quotient (q $CO_2$), indicating the activation of soil microorganism (Pascal and Renin, 1997).With respect of C sequestration in paddy soils was characterized by the increase of SOC in physically protected coarse aggregates in the size of sand particles (Yuan *et al.*, 2004). Concurrently, the application of organic fertilizers paired with the different composts has more potential of enhancing the SOC pool as compared to that of inorganic fertilizer (Held *et al.,* 2005). The higher SOC sequestration rate was recorded in FYM addition compared to inorganic (NPK) alone plots in rice-wheat and maize-wheat cropping system (Kukal *et al.,* 2009). With regards to various organic amendments, ahigher amount of SOC noticed under poultry litter and cattle manure application in rice-wheat-legume rotation compared to farmer's practice of no manure and fertilizer application in rice-wheat-fallow system (Hossain, 2009). In soil profile, the processes were taken in to account include changes in the microbial biomass of C and N, soil enzyme activity, microbial community composition, organic matter decomposition and functional groups of bacteria jointly responsile for trace gas emission in terrestrial and wetland ecosystems (Kundu *et al.,* 2013). Pradhan *et al.* (2015) noticed that soil organic carbon stock rate was higher in daincha + FYM + Vermicompost (46.29 t $ha^{-1}$) and increased sequestration rate. Kraus *et al.* (2016) implied that crop residue incorporation rate of 2.8–3.4 t C $ha^{-1}yr^{-1}$in rice field after harvest is needed to accomplish stable SOC stocks in mixed upland crop–paddy rice systems. Organic materials addition not only maintains the soil fertility but also improves soil structure and soil porosity in heavy soils (Kallenbach *et al.,* 2010; Wu *et al.,* 2019). However, the organic way of fertilization changes the community structure of microbes and affects the decomposition of organic matter (Bao *et al*., 2016; Wei *et al*., 2019). Adding rice straw and green manure to soil are important measures to improve the organic matter content of soil (Wu *et al.,* 2019; Yu *et al.,* 2020). Apparently, some of the research studies have shown that soil respiration was positively correlated with soil DOC and soil microbial biomass carbon (MBC) (Ge *et al.,* 2020).

**Inorganic Fertilizers on $CO_2$ emission in rice production**

The process of carbon mineralization and $CO_2$ evolution in soil has been paid huge attention for its vital effects on global carbon cycle and terrestrial ecosystem functioning (IPCC, 2001; Valentini *et al*., 2000; Jenkinson *et al*., 1991). Many research workers reported that applying 25 or 50 per cent N fertilizer with Glyricidia significantly enhanced the CO2 evolution, indicating a higher respiration rate than the fertilized soil in the upper 0 to 15 cm depth (Maheswara Prasad and Prabhu Prasadini, 2014). The highest $CO_2$-C release was observed on $14^{th}$ day in treatments (fmv) mineral fertilizer application + (fov) manure application (3.94 mg C 100 $g^{-1}$ soil), with respiration the first day (9.44 mg C 100 $g^{-1}$ soil) compared to other treatments (Segda*et al.,* 2014). Whereas 75 per cent N + *Cynaobacteria* significantly increased $CO_2$ evolution (185.36 mg $CO_2$ $g^{-1}$ $dry^{-1}$) compared to control (Abbas *et al.,* 2015). Wang *et al.* (2015) reported that maximum enhancement of rice yield was observed at 600-699 ppm $CO_2$ than lower or higher elevated $CO_2$ levels. Similarly, with respect to the crop stage, the higher rate of CO2 emission (539.6 mg $m^{-2}day^{-1}$) was recorded with chemical fertilizer treatments during the panicle initiation stage compared to other rice growth stages (Redeker *et al.,* 2000). Besides that, the application of N fertilizer and urea significantly influence most biological processes in the soil (Yan *et al.,* 2007), and their application most probably enhanced mineralization, carbon sequestration, and nutrient cycling (Bastida*et al.,* 2006). Concurrently some of the research evidence proved that application of NPK + FYM (2.47 Mg $ha^{-1}$) and NPK + PS (1.41 Mg ha-1) sequestered higher carbon in *Kharif* season (Ghosh *et al.,* 2012). The emission of CO2 and CH4 gases recorded higher value with the application of inorganic fertilizers compare with organic fertilizers (Sampanpanish*et al.,* 2012) and that to eventually increased with the addition of urea, with a maximum at the rate of 250 kg N $ha^{-1}$ (Tang*et al.,*1999). Furthermore, the addition of chemical fertilizer affects the greenhouse gas (GHG) fluxes from soil (Chen *et al*., 2017; Liu *et al*., 2018). Many studies have shown that the application of chemical fertilizers increases soil $CO_2$ emissions (Zhang *et al*., 2019). Chemical fertilizers with different compounds with deviations in C/N ratio may affect soil physicochemical properties and soil CO2 emission (Gwon *et al*., 2019). tang2019). Decreasing conventional rate of untreated urea (CRU) application and the incorporation of organic fertilizer into CRU have the potential for mitigating of CO2 emission and positive effect on the soil microbial functional diversity to improve nitrogen use efficiency of rapeseed (Zhang *et al*., 2020).

**Inorganic fertilizers on $CH_4$ emission in rice production**

The methane emission from inorganic fertilizer (Urea) treated plots recorded <30 g $ha^{-1}day^{-1}$, 12.04 kg $ha^{-1}day^{-1}$and 4.6 kg $ha^{-1}day^{-1}$,during seedling, Panicle Initiation and flowering stages, respectively in rice (Lindau *et al.,* 1993). However, the increasing atmospheric CH4 emissions directly correlate with the per cent of soil sand content ranging from 18.8 to 32.5% and the seasonal methane emissions ranged from 15.1 to 36.3 $gm^{-2}$in rice (Sass *et al.,* 1994). Schimel (2000) found that the application of N fertilizer could increase crop canopy and provide rich organic matter for methanogens, effectively utilizing roots and root exudates as a carbon source for their nourishment.

Methane emission from the NH4 and NO3-N applied plots (mean of 256 mg CH4 $m^{-2}d^{-1}$) were not significantly differ from that of control (mean value of 225 mg CH4 $m^{-2}d^{-1}$) (Dise and Verry, 2001). Nitrogen fertilizers enhanced crop growth and provided more C substrates through organic root exudates and sloughed-off cells to methanogens, leading to increased CH4 production (Inubushi *et al*., 2003). Besides that, inorganic N fertilizer in paddy fields enhanced the growth and activity of methanogens, leading to increasing CH4 emissions (Bodelier and Lannbroek, 2004). Exclusively the application of urea fertilizer and its rate decides the CH4 emission, which is likely a result of an increase in soil pH by urea hydrolysis and a decrease in redox potential probably leads to enhance methanogenic activities

in the paddy field (Dubey, 2005). However, the CH4 emission was hiked with an increased N fertiliser application rate, but a higher rate of N could eventually decrease the CH4 emission in rice (Linquist *et al.,* 2012).
Sampanpanish (2012) opined that the CH4 emission recorded a higher value (3.03 mg $m^{-2}day^{-1}$) in treatments with chemical fertilizer followed by organic fertilizer pellets (2.88 mg $m^{-2}day^{-1}$), organic fertilizer (1.68 mg $m^{-2}day^{-1}$) in rice. Kim *et al.* (2016) revealed that the CH4 oxidation potential significantly increased with increasing N fertilization levels (115-137 kg N $ha^{-1}$), and is highly related to the accumulation of total biomass, straw and root biomass productivities in rice. In controversy, the average CH4 emissions for non-fertilized and fertilized parts were 15.5 and 11.4 mg CH4 $m^{-2}h^{-1}$in the first crop and 16.8 and 11.8 mg CH4 $m^{-2}h^{-1}$in the second crop, respectively (Oo*et al.,* 2015). Whereas, a higher rate of N fertilizers increase the soil salinization and decrease the organic matter content which in turn leads to decrease in CH4 emission in rice (Wang *et al.,* 2016). Various proportions of fertilizers with dissimilarities in C/N ratio may affect soil physicochemical properties, and soil CO2 and CH4 emission (Zhou *et al*., 2017). Kong *et al*. (2019) observed that the application of N fertilizer improved the soil carbon (C) substrate and benefited the methanogens proliferation to improve methanogenic activities and thus promote CH4 emissions. Fertilizers with low C/N ratio can substantially increase the decomposition of residues and contribute to GHG emissions (Zhou *et al*., 2019). Similarly, some research studies have shown that soil respiration was positively correlated with soil DOC and soil microbial biomass carbon (MBC) (Wu *et al*., 2020) and application of nitrogenous fertilizers was not influenced CH4 emission (Lin *et al*., 2021).

**Inorganic fetilizers on carbon dynamics in rice production**

The application of chemical fertilizers is necessary to enhance crop yields and sustain soil fertility (Yadav *et al.,* 2000). Singh and Namdeo (2004) divulged that the application of increased recommended dosage of fertilizers enhanced the nutrient absorption in rice. Kamble *et al.* (2008) documented that the application of 125 per cent of RDF significantly increased the nutrient uptake when compared with lower levels in rice. Scherer (2009) opined that sulphur occurs in organic and inorganic forms and is cycled between these forms through various processes such as mobilization, mineralization, immobilization, oxidation and reduction. Functionally, S significantly influences yield and quality of crops, improves odour and flavours, and imparts resistance to cold, and hence it is generally considered a “quality nutrient” (Usharani*et al*., 2009). The organic source of nutrients has the added advantage of steady and slow release of nutrients for maintaining an ideal C: N ratio, improvement in the water holding capacity and soil microbial biomass, without impairing any adverse residual effects (Yadav *et al.*, 2010). Badar and Qureshi (2014) revealed that composting of organic wastes with the support of microbial inoculation enhanced the total carbohydrates and crude protein contents which might work as a good source of carbon and hydrogen and it may facilitate to restore or increase the fertility of degraded soil. In addition to the single application of chemical or organic fertilizer, the combined application of both is the main measure of agricultural fertilization (Zhou *et al.,* 2019; Qaswar *et al.,* 2020). Soil nitrate nitrogen (NO3 -N) and NH4-N provide essential nutrients for microbes and indirectly affect soil microbes and gas emissions. The process of nitrification and denitrification was affected by the soil pH and affected the activity of soil microbes ( Li *et al*., 2020).

**INM on $CO_2$ emission in rice production**

The application of cow dung (3 t $ha^{-1}$) combines with NPK (15:15:15) recorded eventually increased value of organic carbon from 1.33 to 3.21% and also enhanced soil organic matter, exchangeable ions, effective cation exchange capacity and pH in comparison to untreated plot (Onwudike, 2010). Similarly, Pathak *et al.* (2011) pointed that the application of inorganic fertilizers with organic manure (NPK + FYM) recorded a higher SOC concentration than inorganic fertilizers (NPK) alone in all the longtime experiments. Moharana *et al.* (2012) advocated that the application of FYM either alone or in combination with inorganic fertilizers registered a considerable amount of total SOC accumulated in 10-15 cm soil layer than unfertilized control plots. Concomitantly, the application of NPK either through inorganic fertilizers or through inorganic fertilizer judicially combined with organic manures such as farmyard manure (FYM) or crop residue or green manure improved SOC, particulate organic carbon (POC), microbial biomass carbon (MBC) concentration and as well as their sequestration rate (Nayak *et al.,* 2012). Lal (2014) suggested that the INM improves soil fertility and for healthy crop growth and eventually biochemical transformation of biomass C into SOM or humus.
Maheswara Prasad and Prabhu Prasadini (2014) suggested that the application of 25 or 50 per cent N fertilizer with *Glyricidia* sp. significantly enhanced the CO2 fruition indicating higher respiration rate than the unfertilized soil in the upper 0 to 15 cm depth. Segada*et al.* (2014) disclosed that the higher level CO2-C noticed on the $14^{th}$day in treatments which received mineral fertilizer combined with organic manure (3.94 mg C 100 g-1 soil), with respiration of 9.33 g of C 100 g-1 of soil in the first day. Abbas *et al.* (2015) recorded that 75% N + *Cyanobacteria* application significantly enhanced the CO2 evolution (185.36 mg CO2 $g^{-1}dry^{-1}$) compared to control in rice.

Combined use of chemical fertilizers, 2.0 t C ha-1 fresh rice straw and continuous flooding system performed better results to reduce CO2-C gas emission, increased organic carbon and rice production with maintaining optimum soil pH level with sustainable rice production (Hossain, 2018).

**INM on $CH_4$ emission in rice production**

The maximum CH4 emission rate (4.86 mg $m^{-1}ha^{-1}$) was observed with FYM + urea treatment than, biogas slurry + urea treated plots (Debnath *et al*., 1996). The combined application of NPK and Azolla compost had a significant influence on the accumulation of soil carbon (16.93 g $kg^{-1}$) and capacity of soil carbon storage (28.1 Mg C $ha^{-1}$) with high carbon efficiency ratio (16.9) and also its application significantly enhanced CH4 emission (15.66 %) carbon storage of soil and improved the ability of grain yield (6.55 Mg $ha^{-1}$) over other treatments (Adhya*et al*., 2000). Apparently, the application of organic C through FYM increased the GHG emissions (Pathak *et al*., 2002). Application of FYM @ 12.5 t $ha^{-1}$ integrated with 100% RDF + Azospirillum and Phosphobacteria @ 2 kg $ha^{-1}$ recorded a lower value of 4.4 and 2.06, 7.2 and 1.94 and 2.7 and 1.59 mg $m^{-2}$ $h^{-1}$ $CH_4$ emission during both the day and night time at 40, 80 DAS and at harvest respectively over other organic manure combinations during the *Thaladi*season of the rice crop (Ravikumar and Ganapathy, 2018). The integrated application of urea and oilseed rape cake fertilizer reduced the emission of CO2, whereas enhanced the emissions of CH4 (Lin *et al*., 2021).

**INM on carbon dynamics in rice production**

Application of inorganic fertilizers (NPK 100 %) integrates with organic manure (FYM 10 t $ha^{-1}$) showed a positive influence on all soil properties, especially soil organic carbon Pothare *et al*., 2007). Concurrently, the addition of inorganic fertilizers with various organic manures in rice-wheat system enhanced the aggregation of the soil which paves way for higher storage of SOC content (Singh *et al.,* 2009). A Higher soil quality index (1.61) was noticed with the application of 25 kg nitrogen (N; compost) as well as with the application of 15 kg N (compost) + 10 kg N $ha^{-1}$(green leaf) (Sharma *et al.,* 2015). Akhilesh and Nandan (2016) noticed that a higher soil organic carbon stock (43.77 t $ha^{-1}$) and an enhanced rate of sequestration (2.69 t $ha^{-1}yr^{-1}$) was recorded in the treatment *Dhanicha*+ FYM + Vermicompost application. Cattle manure with high C/N ratio combined with chemical fertilizers significantly increased the microbial biomass C, soil organic C, soil total N, soil mineral N and soil CO2-C flux in black cumin crop (*Nigella sativa* L.) (Salehi *et al.,* 2017). Similarly, Kamp *et al.* (2017) documented that in the long term, cultivation requires balanced fertilization through NPK integrates with FYM, eventually increased the SOC content and SOC stocks and the carbon sequestration potential (1.77 Mg ha-1). The quantities of SOC at the 0 -400 kg of soil m-2 interval decreased under ZT without residue (T1), PRB without residue (T4) and Conventional tillage (T7) treatments evaluated. Stocks of SOC in the top 400 kg of soil m-2 decreased from 7.46 to 7.15 kg of C m-2 represented a change of -0.31 ± 0.03 kg of C m-2 in T1, 8.81 to 8.75 kg of C m-2 represented a change of -0.06 ± 0.05 kg of C m-2 in T4 and 5.92 to 5.22 of C m-2 represented a change of -0.70 ± 0.09 kg of C m-2 in T7 between 2000 and 2016 (Naresh *et al.,* 2017). A higher soil organic carbon with a value of 7.8 and 8.6 g $kg^{-1}$ were recorded with the application of FYM @ 12.5 t $ha^{-1}$ integrated with 100% RDF + Azospirillum and Phosphobacteria @ 2 kg $ha^{-1}$ over other organic manure combinations in the successive years of rice crop (Ravikumar and Ganapathy, 2018).The application of organic manures along with chemical fertilizer and continuous flooded condition paves the way for the highest organic carbon accumulation which is a key factor for improvement of soil quality and minimized environmental pollution (Hossain, 2018).

## Conclusion

Agricultural practices are the major sources of GHGs emission. Hence, it is also mitigate GHGs emissions through reduction in $CO_2$ and $CH_4$ emissions, as well as carbon sequestration. A concrete understanding of how much carbon can be sequestered by different practices is more important inmaking solid decisions about the most appropriate mitigation strategies. Among the various strategies, manure management contributes a considerable share in sustaining soil fertility and reducing GHG emissions. The addition of nutrients throughinorganic fertilizers is inevitable for any crop grown in the conventional cropping method. However, there has been serious concern about long-term adverse effects of incessant and blanket use of inorganic fertilizers on soil structure deterioration, soil health on and above environmental pollution in recent years. The continuous use of imbalanced inorganic fertilizers, is subject to various losses and might be converted into different gas emissions, leading to global warming. Simultaneously, the addition of organic amendments may be very useful in tropical regions, especially in southern parts of India. However, the application of organic manures alone during anoxic condition ultimately enhanced the GHGs emission, whereas, combined with inorganic fertilizers improved the soil organic carbon content rather than the $CO_2$ and $CH_4$ emission. The emission of GHGs are quite inevitable from the total global perspective. But the measuring ways of GHG emission found are complex and uncertain. Therefore, there is a need for user-friendly, cost-effective methods for GHGs quantification that work across regions and systems. Though there are many significant opportunities for GHGs mitigation in agriculture, numerous obstructions need to be conquered. It would also require increased Research and Development efforts on mitigation and adaptation, development activities, manure and land-use management changes.

**Conflict of interest**

The authors declare that they have no conflict of interest.

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