Chapter 3
Greenhouse Gases Emission from Rice Paddy Ecosystem and their Management

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1 Introduction

The agriculture sector is one of the major sources of Greenhouse gases (GHGs). According to Sharma et al. (2011), agriculture sector contributed 19 % of total CO_2 equivalent emissions in India in 2007 and within the agriculture sector, rice cultivation is a major source of emission of Greenhouse gases in the form of CH_4. At several regional and global conventions, the options for the mitigation of emission of GHGs have been discussed widely. Several studies indicated that methane emission from rice fields can be mitigated through modification of crop cultivation practices like manure and fertilizer management, irrigation management, practice of 'No Tillage', 'Reduced Tillage', adoption of conservation agriculture, crop rotation and various alternative crop management measures, etc. However, in most of the cases, the yield of the crop is often negatively impacted. Improvement of crop varieties has been considered by many scholars as a viable option for reduction of methane emission without impacting the productivity of the crop as methane flux from rice fields is dependent on various cultivar specific properties like properties of root exudates, root porosity and permeability, features of the aerenchyma tissue, stage of the crop growth, methane conductance through the stem, photosynthate allocation efficiency, etc. Modification of such cultivar specific properties that can significantly reduce CH_4 emission, through appropriate crop improvement techniques should be the future research arena for mitigation of GHG emission from rice cultivation.

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N. Tuteja, S. S. Gill (eds.), *Crop Improvement Under Adverse Conditions*,
DOI 10.1007/978-1-4614-4633-0_3,

2 Emission of Greenhouse Gases (GHGs) from Agriculture

According to the Inter-governmental Panel on Climate Change–Assessment Report 4 (IPCC–AR4 2007), the agriculture sector had contributed 10–12 % of the total anthropogenic GHG emissions in the year 2005. Since 1990, CH_4 and NO_2 emissions from agriculture sector are rising at the alarming rate of 58 Mt CO_2 equivalent/yr (US-EPA 2006a). Agriculture sector's contribution is more significant when emissions from individual sources are considered separately. The agriculture sector contributed 58 % of the total N_2O and 47 % of the total CH_4 emissions in the year 2005 (IPCC–AR4 2007). Emission from enteric fermentation and submerged rice fields constitutes the major source of CH_4 whereas emission from soil constitutes the single largest source worldwide (US-EPA 2006a). Biomass burning and manure management also account for a significant amount of global GHG emission. Net CO_2 emission from agriculture sector is less than 1 % of the global anthropogenic emission (US-EPA 2006b). Terrestrial plants also emit methane, global flux 62–263 Tg/yr, contributing 10–45 % of total global methane emissions (Keppler et al. 2006). Terrestrial plants emit methane through detached leaves as well as whole plant (Keppler et al. 2006; Whiticar and Ednie 2007). Transpiration is the dominant mechanism helping such emission pathway through leaves via xylem. Stiehl-Braun et al. (2011) studied the spatial distribution of methane-oxidizing bacteria (MOB) and proved that methane consumer bacteria can escape the effect of nitrogen (N) fertilization by shifting their zone of activity into deeper soil layers. Nitrogen fertilization and global methane cycling are interdependent and interlinked in both wetland conditions as well as in upland situations. Methanogenic archaea in wetlands is one of the major sources of methane whereas upland soil is a major C sink (Bodelier et al. 2011).

Developing countries contributed around 97 and 92 % of total global emissions from rice production and burning of biomass while developed countries contributed 52 % of total GHG emission from manure management (US-EPA 2006a). South and East Asian nations contributed 82 % of the total CH_4 emissions while countries from Sub-Saharan Africa and Latin America and the Caribbean have contributed about 74 % of total emissions from biomass burning. Yan et al. used the Tier-1 method as described in IPCC (Eggleston et al. 2006) guidelines for estimating global methane emissions and Monte Carlo simulation for estimating the uncertainty range. They have estimated that the total global CH_4 emission in the year 2000 was about 25.4 Tg/yr. They have further calculated that if all of the continuously flooded rice fields were drained at least once during the growing season, a reduction of 4.1 Tg CH_4/yr could be possible (Table 3.1).

Jiang et al. (2000) used The Asian-Pacific Integrated Model for analyzing the long-term Greenhouse gas (GHG) emission scenarios depending on alternative development paths in the developing countries of the Asia-Pacific region. They have taken into account four differeknt scenarios, namely Catch-Up Scenario (Scenario C), Domestic Supply Scenario (Scenario D), Short-cut Scenario (Scenario S) and Regional Equity Scenario (Scenario E). They have estimated that the growth rate of GHG emissions in the Asia-Pacific region is significantly higher than the overall

Table 3.1 Estimated emissions from global rice fields (Tg CH_4/yr)

Country	Irrigated rice	Rain-fed and deep water rice	Total
India	7.41	0	7.41
China	3.99	2.09	6.08
Bangladesh	0.47	1.19	1.66
Indonesia	1.28	0.38	1.65
Vietnam	1.26	0.39	1.65
Myanmar	0.80	0.36	1.17
Thailand	0.18	0.91	1.09
Other Monsoon Asian Countries	2.32	0.67	2.99
Rest of the World	1.2	0.49	1.7
Total	*18.9*	*6.49*	*25.39*

global emission growth rate and under all the scenarios CO_2 emission in year 2100 will be higher than the year 1990 level in the region.

Till date, the actual mechanism of N_2O emissions is not well understood and its emission coefficient calculated by IPCC methodology shows wide variability (Kroeze et al. 2003). The IPCC methodology led to over-estimation of N_2O emissions from legumes (Gregorich et al. 2005).

The CH_4 emissions from rice paddy cultivation under alternate scenarios are more or less stable around 4 Tg/yr. In India, there are diverse cultivation practices in various parts of the country depending upon water availability. Continuously flooded irrigated farming contributes to CH_4 emissions at the rate of 0.0251Gg CH_4/km^2/yr while upland farming contributes very negligible amount of CH_4 emissions (Garg et al. 2001; Fig. 3.1).

The major CH_4 sources in India are livestock farms, paddy fields, coal mining, municipal solid wastes, natural gas exploration and gas flaring and biomass burning etc. In the year 2000, CH_4 (18.63 Tg) and N_2O (0.31 Tg) emissions contributed 27 and 7 %, respectively, to India's CO_2 equivalent Greenhouse gas (GHG) emissions (Garg et al. 2003). The major N_2O emission sources include use of synthetic fertilizers in agricultural fields, indirect emission from atmospheric deposition of NH_3 and NOx, biological N_2-fixation, coal combustion, oil products combustion, crop residue burning and industrial activities, etc. However, emissions from synthetic fertilizer use contributed the maximum percentage (67 %) among all other sources. In the year 2003, the agriculture sector contributed about 65 % of CH_4 emissions and above 90 % of N_2O emissions in India (Garg et al. 2003; Garg et al. 2002).

Parashar et al. (1997) have estimated methane emission from rain-fed low land paddy fields is about 25 t/Km^2, while irrigated rice fields and deep water rice fields contributed on an average 32.46 t/Km^2 and 19 t/Km^2, respectively. The study showed that in 1995, Greater Mumbai (0.51 Tg), Midnapore, WB (0.24 Tg), Bilaspur, MP (0.17 Tg), Burdwan, WB (0.16) and Raipur, MP (0.15 Tg) were the top five districts in terms of methane emission in India. They had also analyzed sectorial emissions in all Indian districts and showed that Midnapore (West Bengal); Cuttack

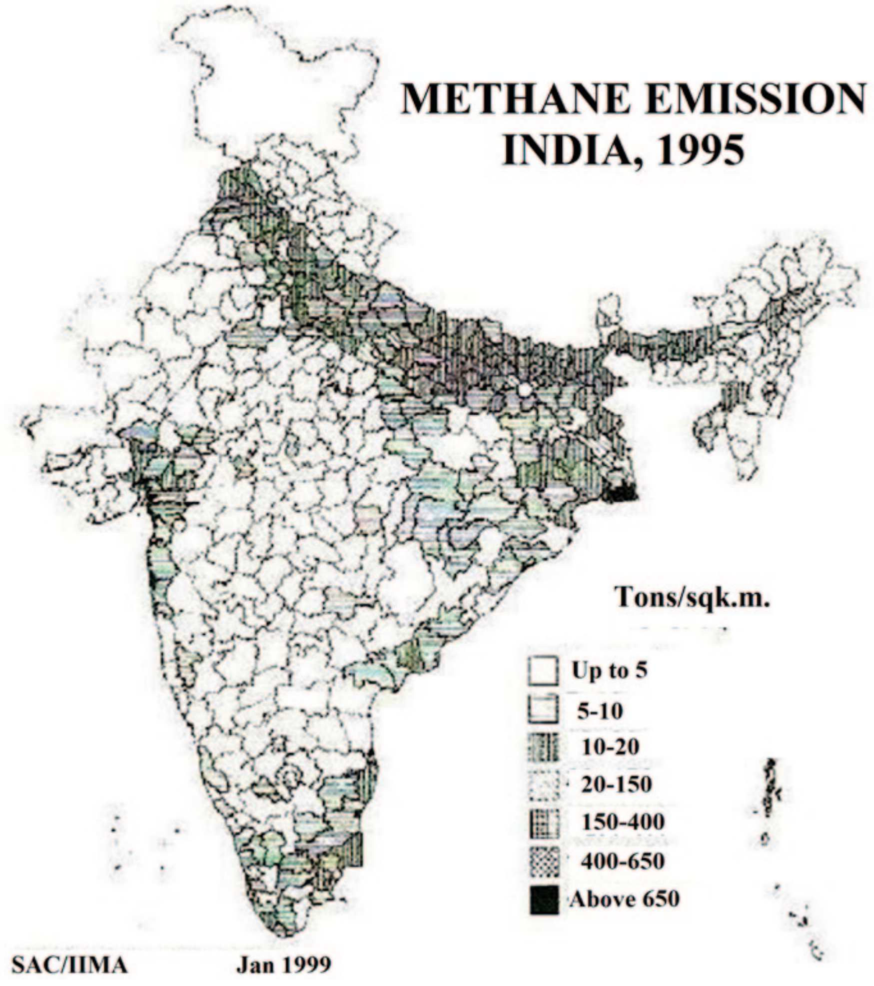

Fig. 3.1 Methane emission in India in 1995. (Source: Garg et al. 2001)

(Orissa), Raipur and Bilaspur (Chattisgarh) were the major methane emitting districts in India.

Garg et al. (2001) have calculated that the total CH_4 emissions in India increased from 17 Tg in 1990 to 18 Tg in 1995. Garg et al. (2001) have analyzed GHG emissions from large point sources (LPS) all over India and showed that in terms of CO_2 equivalent emissions, power plants, steel factories and transport sector together contributed about 47.9 % and agricultural sector, including livestock and synthetic fertilizer sources, contributed about 23.5 % of the total GHG emissions. Garg et al. (2001) have also shown that agriculture-related activities are responsible for about 90 % of Nitrous oxide emissions. The major sources were use of nitrogen fertilizers in agricultural fields (60 % of total NO emissions), biomass burning (10 % of total NO emissions), indirect soil emissions (10 % of total NO emissions) and livestock-related emissions.

3 Methane Emission from Rice Cultivation

Rice paddy field is an important source of methane. Many field and lab based studies have been carried out around the world to explore various aspects of methane production and emission from rice paddy soils. Wassmann et al. (2000a) have studied methane emissions from five different Asian countries (China, India, Indonesia, Philippines, and Thailand) and reported that climate and soil conditions play important roles in regulating methane emission potential from rice fields. They have used automated closed chamber method for estimating methane emissions from the rice fields. Their study revealed that low temperature and subtropical climate limited CH_4 emission in Northern China and northern India whereas tropical stations (Maligaya, Philippines; Beijing and Hangzhou, China) registered higher emission rates (300 kg CH_4/ha^{-1}/season^{-1}).

CH_4 emission from rice fields is highly sensitive to existing water regime, local variations in crop management and quality of organic inputs so that in most of the cases their cumulative impact overpowers the impact of soil and climate (Wassmann et al. 2000a). The spatial variations in CH_4 emissions from different rice-growing areas have also previously been reported (Parashar et al. 1996; Yagi et al. 1994).

Wassmann et al. (2000b) showed that distinct period within the season can help to reduce CH_4 emission significantly (20–80 %) in irrigated rice cultivation. Chareonsilp et al. (2000) reported that methane fluxes from deepwater rice fields is lower than that of irrigated rice fields but due to longer seasons and continuous flooding conditions, total emission from deepwater rice fields is quite high, i.e., about 99 kg CH_4/ha^{-1}/season^{-1}. Emission of methane from rain-fed rice fields is much lower than that of irrigated rice fields (Setyanto et al. 2000). Garg et al. (2011) estimated that in the year 2008 India's total methane emission was about 20.56 Tg and agriculture sector contributed 23 % of India's total GHGs emission. The study also showed that Uttar Pradesh and Andhra Pradesh were the two highest methane producing states and Mumbai and Anugul (Orissa) districts were the two highest methane producing districts in India.

4 Nitrous Oxide Emission from Agricultural Soils

Flooded rice fields are not the potent source of N_2O emissions because of prevailing anaerobic conditions (Granli and Bockman 1994). Emission of N_2O starts only when the fields are drained and aerobic conditions are created. Use of N-fertilizers increases the rate of N_2O emissions from rice fields (Kumar et al. 2000). Sharma et al. (1995) estimated that N_2O–N emissions from irrigated and upland paddy fields in India are about 0.004–0.21 Tg/yr^{-1} and 0.002–0.01 Tg/yr^{-1}, respectively. However, the emission of CH_4 can itself act as a check on N_2O formation in flooded rice soil (McCarty et al. 1991). Ghosh et al. (2003) reported that in New Delhi, India, total CH_4 emission under upland conditions is in the range of 24.5–37.2 kg/ha^{-1} while N_2O fluxes varied in the range of 0.18–100.5 μg m^{-2} ha^{-1} with CV 69–143 %, and application of N-fertilizers invariably increased the rate of N_2O emission. Application of nitrification inhibitors like DCD can reduce N_2O emission up to 10–53 % under New Delhi conditions by reducing the availability of NO_3-(Ghosh et al. 2003; Pathak and Nedwell 2001). Kumar et al. (2000) reported that application of DCD with urea and $(NH_4)_2SO_4$ could reduce N_2O–N emission by 11 and 26 % respectively in irrigated transplanted rice grown on Typic Ustochrepts soil in New Delhi, India. Malla et al. (2005) studied the efficacy of five different nitrification inhibitors (neem cake, thiosulphate, coated calcium carbide, neem oil coated urea and DCD) in Indo-Gangetic plains in rice-wheat system and reported that DCD and Ca carbide were more efficient in reducing GWP potential than thiosulphate, neem oil, and neem cake. Bhatia et al. (2010) reported that application of nitrification inhibitors like S-benzylisothiouronium butanoate (SBT–butanoate) and S–benzylisothiouronium furoate (SBT–furoate) could reduce GWP of wheat soil by 8.9–19.5 % under both conventional and no-tillage practice. DCD, one of the most potent nitrification inhibitors, which has been commercially used in Japan and Germany (Bharti et al. 2000) produces non-toxic byproducts upon decomposition (Amberger 1989). The mitigation practices for CH_4 emission and N_2O emission are competitive to each other (Bronson et al. 1997) so a balanced approach should be followed to minimize the Cumulative Radiative–Forcing of both the gases.

Pathak and Nedwell (2001) have shown that application of nitrate (NO_3-N) fertilizers like calcium ammonium nitrate (CAN) in aerobic conditions and ammonium (NH_4-N) fertilizers like ammonium sulphate and coated urea in wetland conditions can significantly reduce N_2O emission. Li et al. (2009) reported that the time of application of nitrification inhibitor, DCD, can increase rice yield as well as reduce the GWP of CH_4 and N_2O emissions from rice fields. They studied the impact of application of DCD at three different stages of crop growth, i.e., Land preparation, tillering, panicle initiation. They have found out that application of DCD at tillering stage had maximum inhibitory effect on N_2O emission (56 % reduction) while application during panicle initiation could reduce N_2O emission efficiently. Application of DCD as basal reduced CH_4 emissions by 35 %.

Soils with high SOM emit more N_2O (Bouwman et al. 2002) and carbon and nitrogen cycles depended on each other in the soil environment (Li et al. 2005a). N_2O is released during both nitrification and de-nitrification. Nitrification inhibitors like Nitrapyrin, DCD and DMPP could be mixed with urea for effectively reducing the N_2O emissions (Pain et al. 1994). No tillage system reduces CH_4 emission from soil as any disturbance in soil environment increases decomposition rate of soil C (West and Post 2002) but effect of no-tillage on N_2O emission is primarily determined by soil and climatic conditions (Marland et al. 2001). Studies indicated that there is an inverse relationship between reduction of CH_4 emission and N_2O emission (Monteny et al. 2006). Zoua et al. (2007) estimated that about 29.0 Gg N_2O–N is emitted during the crop growing period from the rice fields in China which accounts for about 7–11 % of total annual emissions in China. The study also reported that among the different water management systems practiced in China (i.e., continuous flooding (F), flooding-midseason drainage-reflooding (F-D-F) and flooding-midseason drainage-reflooding-moist intermittent irrigation, but without

Table 3.2 GHG emissions from India, Thailand and Philippines. (Source: Gadde et al. 2009)

Country	GHG emission from open field burning (t CO_2 eq/yr.)	Total GHG emission (t CO_2)	% contribution from open field burning
India	556,165	1,218,928,500	0.05
Thailand	425,225	231,546,484	0.18
Philippines	412,803	6,345,154	0.56

water logging (F-D-F-M)), F-D-F and F-D-F-M systems significantly increased the N_2O emissions. A similar result was reported by Wange et al. Their study reported that water management system significantly influences the N_2O emissions from rice fields. The study reported that average N_2O emissions from rice fields under mid-season drainage and continuous flooding treatments were 0.41 kg/N/ha^{-1} and 0.28 kg/N/ha^{-1} respectively. The study showed that N_2O emission gets enhanced mainly in the transition phase of the water management system and 50 % emission reduction under both water management systems can be achieved by integrated application of N fertilizers and rice straw.

5 Emission of GHGs due to Field-Burning of Crop Residue

Burning of crop residue releases GHGs (CO_2, CH_4, and N_2O), other trace gases (CFCs, O_3, CO, Non methane hydrocarbons) and particulate matter into the atmosphere. Sahai et al. (2007) estimated that in the year 2000, about 85,623 Gg of dry wheat residue was generated, of which about 21,406 Gg was openly burnt leading to emission of about 68 ± 51 Gg, 34435 ± 682 Gg CO_2 and 14 ± 9 Gg N_2O. The trace gases released during burning of crop residue also have negative impact on human health and natural environment (Cheng et al. 2000). India's NATCOM (2004) used IPCC methodology and estimated 56, 1 and 40 Gg of CH_4, N_2O and NOx in the year 1994 from in situ burning of wheat residue (Table 3.2).

Gadde et al. (2009) estimated GHG emissions from crop residue burning in three countries namely India, Thailand and Philippines. They reported that 23, 48 and 95 % of the crop residue produced is openly burnt in India, Thailand and Philippines respectively.

6 Modelling GHG Emission from Agriculture

Various models have been used for estimation of various GHGs e.g., CH_4 emission, MERES (Matthews et al. 2000), DNDC (Li et al. 2005b), DayCent (Del Grosso et al. 2009), InfoCROP (Aggarwal et al. 2004) and WNMM (Li et al. 2005b).

The IPCC Tier I is widely used by various scientists for estimating GHG emissions. However, DNDC is one of the very efficient process based biogeochemical models for predicting C sequestration and trace gas emissions from agricultural lands (Li et al. 1992). The DNDC model can predict about N_2O, CO_2, CH_4, crop production, NH_3 volatilization and NO_3^-leaching. Other process-based models include TEM, CENTURY, and ROTHC, etc. The DNDC model has six sub-models, including soil climate, plant growth, decomposition, nitrification, denitrification and fermentation sub-model. Zhang et al. (2011) used DNDC model for quantifying methane emissions from Sanjiang province (North east China) and reported that the region had emitted 0.48–0.58 Tg CH_4-C in 2006. Stephen et al. (2009) used DAYCENT model for estimating GHG emissions from non-rice crops like corn, wheat and soybean. DAYCENT model considers not only N inputs but also other factors like soil texture class, plant N demand, timing of N application, moisture stress, temperature and organic matter decomposition rates for estimating rate of N_2O emission.

7 Mitigation of GHG Emissions from Agriculture

Mitigation of GHGs from agriculture ecosystems without hampering the crop yield is a big challenge. Many research works have been carried out across the world to address this challenge. Many means of mitigation of GHGs from agriculture ecosystems have been identified and tested. Following section will address some of those important mitigation options for GHG management in agriculture ecosystems.

7.1 Through Sequestration of Carbon in Soils

Adoption of agronomic practices like extended crop rotation, cultivation of improved varieties, and use of perennial crops can increase carbon (C) storage significantly in various types of soils (Follett 2001). 'No Tillage' system reduces CH_4 emissions from soil as any disturbance in soil environment increases decomposition rate of soil C (West and Post 2002) but the effect of no-tillage on N_2O emissions is primarily determined by soil and climatic conditions (Marland et al. 2001). Studies have indicated that there is an inverse relationship between reduction of CH_4 emission and N_2O emission (Monteny et al. 2006). In Eastern Canadian soil, crop rotations involving alfalfa had highest amount of carbon stored in the soil (513 kg C/ha/yr) over 20 years. While corn-corn-soybean-soybean rotation had stored the lowest amount, different management practices had significant effect on GHG emissions (Meyer-Aurich et al. 2006). Various tillage practices have very insignificant effect on soil carbon storage in Eastern Canadian soil (Angers et al. 1997; Yang and Kay 2001). Meyer-Aurich et al. (2006) showed that inclusion of alfalfa into crop rotation can mitigate around 2000 kg CO_2 equivalent/ha/yr. Lal (2010) estimated that the global cropland soil can sequester 0.61–2 Pg/yr and soil organic carbon (SOC) concentration in root zone soil of about 1.1 % is essential for maintaining optimum soil health and agronomic conditions. Soil C sequestration can reduce CO_2 concentration in the atmosphere by locking the C as humus in the soil system for quite a long time. Depletion of SOC depends on climate, soil type and cultural management practices. Adoption of proper management practices can improve the SOC pool as well as increase productivity and enhance soil resilience to adapt to changing climatic scenarios (Lal 2004). Lal et al. (2006) estimated that an increase in SOC by 1 t/ha could increase grain yield by 6.4 million t in Africa and 11.7 million t in Asia. Lal (2011) estimated that increase of 1 t C/ha/yr in the rhizospheric soil can increase foodgrain production by 24–32 million t in the developing countries of the world. The study also quantified the potential of soil C sequestration of the agro-ecosystems of the world to be approximately 1.2–1.3 billion t C per year. The study also showed that if the SOC pool is increased by 10 % over the twenty-first century, it can cause reduction of 110 ppm of atmospheric CO_2 concentration (one billion t of soil C = 0.47 ppm of atmospheric CO_2). Hansen et al. (2008) showed that bio-sequestration can reduce CO_2 concentration by 50 ppm by the year 2150.

7.2 Conservation Agriculture

The concept of Conservation agriculture (CA) was put forward by FAO for addressing the growing concern over sustainable agriculture. Conservation agriculture is a package of management practices that mainly includes reduced tillage, No tillage, direct seeding, soil cover (i.e., cover crops, relay crops, intercrops) to manage soil erosion, improvement of soil health, crop rotation for controlling weeds, etc., (Derpsch 2001). These practices lead to increase in soil organic carbon. No tillage system is better than reduced tillage system as far as accumulation of soil C is concerned (West and Post 2002). Under ‘No Tillage’ system, SOC gets accumulated in the top soil that creates a vertical stratification of soil C which regulates the soil microbial activity (Dennis et al. 1994; Stockfisch et al. 1999; Moreno et al. 2006). Conservation agriculture helps to improve soil’s physical properties like porosity, soil structure, and water holding capacity (Medvedev et al. 2004; Josa et al. 2005). Chivenge et al. (2007) studied the effect of tillage and management practices on SOC dynamics in red clay soil and sandy soil and reported that tillage disturbance is the major factor influencing the C dynamics in agricultural soil. The study also indicated that practice of Conservation agriculture can improve soil C status and maintain long-term sustainability. Ghimire et al. (2011) conducted an experiment in Chitwan Valley of Nepal and reported that ‘No Tillage’ system is far better than that of conventional tillage system for C sequestration in rice–wheat cropping system. Datta et al. (2011) showed that crop diversification can reduce cumulative methane emission and also reported that rice potato sesame was most suitable cropping system for mitigation of greenhouse gas emissions. The study suggested that methane fluxes from different cropping systems and reported that GWP of rice–rice system is very high whereas rice-potato-sesame system is most profitable in terms of total revenue ($ 1248.21 per ha) as well as C-credit ($38.60 per ha).

7.3 Water Management

Practice of midseason drainage has been followed in China since 1980s and studies showed that it resulted in 40 % CH_4 emission reduction i.e., about 5 Tg CH_4/yr (Li et al. 2005b). However, the effectiveness of water management in reducing CH_4 emissions varied from place to place. Midseason drainage also increased N_2O emissions that offset a part of Greenhouse gas radiative forcing benefit (nearly 32 %) obtained through reduction in methane emission. Maximum Greenhouse gas radiative-forcing benefit can be gained when midseason drainage is applied to soil with low organic content and high clay content (Li et al. 2005b). Husin et al. (1995) studied the influence of various irrigation practices (continuous flooding, intermittent irrigation, and saturated soil conditions) on CH_4 flux from rice fields in Java and Indonesia and proved that the water management treatments significantly influences the average daily methane fluxes. The study showed that CH_4 flux in intermittently irrigated rice fields was 53 % lower than that of continuously flooded fields. Soil Eh status can be maintained easily by altering water management practices. Midseason drainage can increase Soil Eh to the oxidative state (to the level $+450$ mV from -160 mV) in just a few days that suppressed the methanogenesis process in the rice soil (Reddy et al. 1989; Patrick and Jugsujinda 1992).

Yagi et al. (1998) studied the impact of water percolation on CH_4. The study suggested that CH_4 emission rate got reduced significantly with an increase in the percolation rates. Yu et al. (2004) reported that under non-flooding (but wet) irrigation system, cumulative global warming potential of rice fields can be reduced up to about 72 %. Nelson et al. (2011) reported that midseason drainage can reduce methane emission effectively as well as promote methane oxidation process which together can reduce Greenhouse gas emissions by 75 million t of CO_2 equivalent. Tyagi et al. (2010) studied the impact of four different types of water management systems (continuous flooding, tillering stage drainage, midseason drainage and multiple-drainage) on CH_4 efflux from rice fields. The study showed that midseason drainage and multiple-drainage are highly effective in reducing methane emissions from rice soil. The study also reported that midseason drainage and multiple-drainage can mitigate GWP of rice soil by 41 and 37 % respectively. Itoh et al. (2011) studied the impact of prolonged midseason drainage on methane flux from Japanese rice fields and reported that seasonal CH_4 emissions and 100-year GWP can be reduced to approximately 69.5 and 72 % respectively by alternative water management without any significant decrease in the grain yield.

7.4 Direct Seeding of Rice

Corton et al. (2000) reported 18 % CH_4 emission reduction by utilizing direct seeded rice practice in Philippines. Wassmann et al. (2004) showed that DSR practice along with a midseason drainage system practice can reduce CH_4 emissions by 50 %. Ahmad et al. (2009) reported that DSR plus no tillage is a promising option for reducing GWP of rice soil.

7.5 Fertilizer Management

Rath et al. (1999) studied methane emissions for same cultivar 'Gayatri' under rainfed lowland and irrigated condition using different fertilizer management practices (Prilled urea, prilled urea + nimin, Urea super granule and control). They reported that application of nitrification inhibitor, nimin with urea, reduced CH_4 emissions effectively by inhibiting the autotrophic oxidation as earlier reported by Sahrawat and Parmar (1975). Urea super-granule application at the base of the plant is also an efficient option for reducing emission. Bronson et al. (1991) reported that wax coated Calcium carbide can reduce CH_4 emission by releasing acetylene that acts as inhibitor of methanogenesis. Application of muriate of potash reduces active reducing sunstances, Fe^{2+}content and redox potential whereby apart from increasing the grain harvest, it also reduces methane emissions significantly (Babu et al. 2006).

7.6 Silicate Fertilization

Ali et al. (2008) studied the influence of silicate iron slag on rice (*Oryza sativa, cv. Dongjinbyeo*) in Agronomy Farm, Gyeongsang National University, South Korea. Their study showed that silicate fertilization @ 4 Mg/ha could reduce CH_4 emissions by 16–20 % and at the same time increasing the yield by 13–18 %. The growth of the rice plant was enhanced due to increased availability of nutrients. CH_4 emission was limited due to higher concentration of ferric oxides which acted both as oxidizing agent and electron acceptor (Ali et al. 2008). They have reported a strong negative correlation between CH_4 flux and free iron and active iron concentration in soil. Other studies on silicate fertilization indicated that iron oxide suppresses production of organic acid by acting as electron acceptor (Asami and Takai 1970; Watanabe and Kimura 1999). Ali et al. (2009) studied the influence of silicate fertilization on methane production under conventional and no-tillage conditions in Korean paddy fields. Their study showed that methane emission was reduced under conventional and no-tillage conditions by 54 and 36 % with silicate slag application @ 4 Mg/ha^{-1}. Silicate fertilization also reported to improve soil porosity and redox potential, active tillering rate, root volume and leaf photosynthetic rate. Nouchi (1994) and Aulakh et al. (2000) reported that CH_4 emissions get reduced drastically at grain maturation stage due to reduced gas conductivity as well as reduced photosynthetic activity.

7.7 Efficient Management of Manure

Since CH_4 is produced under anaerobic conditions, so by improving organic matter management or incorporating organic matter into soil during off-season drained period, CH_4 emissions can be reduced significantly (Kalra et al. 1996). Debnath et al. (1996) showed that by application of fermented manure like biogas slurry, CH_4 emissions from rice fields can be reduced without hampering the productivity.

8 Crop Improvement for Reducing GHG Emissions

Perhaps one of the most challenging means of mitigation of GHG emissions is the crop improvement. Scientists are pursuing this field of research quite vigorously. Though not much success has been achieved, yet a strong database has certainly been created through worldwide researches on this topic. Many scientists and institutions are working on this aspect for the mitigation of GHG emissions. Like many parts of the world, efforts are on in India also to develop crops with certain characteristics so that the plants emit less GHGs without causing any reduction in the yield.

8.1 Plant Physiology and Molecular Biological Approach

The aerenchyma tissues in the leaf, roots and clum of rice plants act as an efficient channel for gaseous exchange between soil and atmosphere (Raskin and Kende 1985). Satpathy et al. (1998) also reported a negative correlation between oxidase activity of the root tip and CH_4 flux. Higher oxidase activity in the vicinity of the rice plant roots inhibits methanogenesis and increases CH_4 oxidation (Ota 1970). Lueders and Friedrich (2002) reported that addition of electron acceptors stimulates microbial population that is competitive to methanogens by suppressing methanogenic metabolic pathways, thereby reducing methane emission from rice fields. Application of mycorrhiza and methanotrophs can effectively reduce methane emission from rice fields by suppressing methanogen population in rice soil (Lakshmanan et al. 2009).

Rice Cluster I (RC-I) refers to the orders *Methanosarcinales* and *Methanomicrobiales* that carry the *mcr-A* gene coding for methyl coenzyme M reductase (*mcr A*; Grosskopf et al. 1998a). This group of bacteria, abundant in soil in all parts of the world, is responsible for CH_4 emissions through the process of acetoclastic methanogenesis (conversion of acetate to CH_4) or hydrogenotrophic methanogenesis (conversion of H_2O plus CO_2 into CH_4;Conrad et al. 1993). Grosskopf et al. (1998b) and Kudo et al. (1997) studied the *16S rRNA* sequence of Rice Cluster I.

8.2 Genetic Engineering Approach

C_4 crops can assimilate more CO_2 than that of C_3 crops due to specialized C_4 metabolism cycle and can reduce photorespiration by 80 % by increasing bundle sheath CO_2 level significantly (Kajala et al. 2011). In recent times, installation of C4 mechanism into staple food crops like rice, wheat and potato is considered as the futuristic answer to the problem of increasing food insecurity in today's world. International C4 Consortium led by International Rice Research Institute (IRRI) has been trying to install two-cell C4 cycle in rice for achieving higher productivity and higher resource utilization efficiency. This task itself is an enormous challenge to the scientific community, however the conversion is not impossible as all C4 cycle enzymes are found in C3 plants at low level and no new genes are associated with C4 pathway (Sage 2004; Brown et al. 2010). The aim of such a research is to down-regulate the expression of mesophyll cells and change the leaf anatomy i.e., increased vein density and number of M cells in between veins as low as possible. This feature of the C4 rice would help reduce emission of methane as M cells play an important role in determining the methane conductance through the rice plant.

8.3 Temperature Regulation

Various studies have reported a positive correlation between CH_4 flux and soil temperature (Conrad et al. 1989; Sass et al. 1991) but no significant relation is found between methane emissions and amount of light incident on the rice plant (Nouchi et al. 1990). Gas permeability of root epidermal layers and structure of aerenchyma gets adversely affected by aging (Armstrong 1971; Arikado et al. 1990). At maturity, CH_4 emission is reduced due to choking of aerenchyma but increased air temperature during maturation of crop does not play any significant role (Watanabe et al. 1994).

Hosono et al. (1997) reported the effect of temperature on the rate of CH_4 emission. Their study showed that when temperature was increased from 15 to 30 °C, the methane diffusion increased by 2–2.2 times. The study also suggested that air temperature has much less effect on CH_4 conductance than that of rhizosphere soil temperature. The correlation between soil temperature and conductance was reported to be statistically significant ($p<0.01$). At 28 °C soil temperature, conductance was six times higher than that of at 18 °C.

8.4 Water Management

It has been reported that the degree of water submergence could influence the rate of methane flux from rice plants (Wang et al. 1993). Wang et al. (1997a) have studied

Table 3.3 Variation in CH_4 emissions with various levels of submergence. (Source: Wang et al. 1997b)

Water depth (cm)	% nodes submerged	CH_4 emission (%)
5.5	0	100
12.5	30	77
26.5	67	16
38	100	1

the role of aerenchyma of leaves, nodes and panicles in methane emissions. Emission through the rice plants is controlled by diffusion.

Wang et al. (1997b) reported that under various degree of submergence, the emission rate gradually decreases and it completely stops under complete submergence conditions. The study also proved that CH_4 emission through panicles is far less than that of cracks and porous structure at nodes and increasing submergence reduces CH_4 emissions temporarily until the concentration gradient is readjusted to above water emission sites (Table 3.3).

8.5 Cultivars Development

Das et al. (2008) studied methane emission in traditional cultivar 'Agni' and modern improved cultivar 'Ranjit' under irrigated condition in North Bank Plain Zone of Assam, India. They reported that Agni cultivar emitted more methane gas because of its poor capacity for allocation of photosynthate to the developing grain, which led to increased rhizo-deposition, thus increasing the CH_4 emission whereas 'Ranjit' cultivar emitted less CH_4 it being able to allocate photosynthate efficiently towards panicle and developing grains having smaller root length and smaller leaf area.

Wang et al. (2000) studied three rice cultivars and reported that IR65598 cultivar had higher oxidative activity in the rhizosphere than IR72 and Chiyonishiki. They studied the rate of CH_4 emission in different growth stages. In the tillering stage, all the cultivars showed very low emission rate but at flowering and ripening stage, IR72 and Chiyonishiki had significantly higher emission rate than IR65598. About 60–90 % of methane emitted from rice fields is transported through aerenchyma of the rice plants (Holzapfel-Pschorn and Seiler 1986). Rice plants act as a conduit for CH_4 emissions as well as source of methanogenic substrates. Yunsheng et al. (2008) studied four cultivars (IR65598, IR72, Dular and Koshihikari) under elevated CO_2 concentration in Tsukuba, Japan, and reported that under elevated CO_2 conditions, CH_4 fluxes increased by 10.9–23.8 % and daily CH_4 flux was highest for Dular and lowest for Koshihikari. Mitra et al. (1999) studied six different rice varieties (Pusa 933, Pusa 169, Pusa 1029, Pusa Basmati, Pusa 677 and Pusa 834) in New Delhi and reported that Pusa 933 emitted maximum CH_4 and Pusa 169 variety the minimum. These studies show that use of different cultivars can be a good option for mitigation of CH_4 emission from the rice fields. They also provide clues that through '*on'* and/or '*Off*' the shelf techniques, new plant types could be developed with less methane emitting potentials (Table 3.4).

Table 3.4 Yield and total CH_4 emissions from six rice varieties. (Source: Mitra et al. 1999)

Variety	Total methane emission (Kg/ha)	Yield (t/ha)
Pusa 169	15.63	6.5
Pusa Basmati	26.31	4
Pusa 834	24.02	6.4
Pusa 1019	26.97	4.8–7.1
Pusa 677	16.91	3.2–7.3
Pusa 933	27.24	5.5–7.5

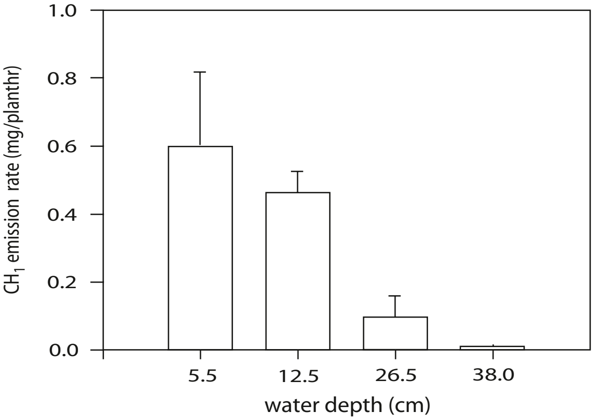

Fig. 3.2 Methane emission from rice culms at different depths of flood-water (mean ± SE, $n = 3$). (Source: Wang et al. 1997b)

The capacity of methane emission varies widely among rice cultivars (Shalini et al. 1997; Sigren et al. 1997; Kesheng and Zhen 1997) but only variation in CH_4 transport capability is insufficient to explain the variability of CH_4 emission potential among different cultivars (Aulakh et al. 2000b).

8.6 Manipulation of Plant Root Properties

Root exudation ability of different cultivars (Wang et al. 1997b; Wassmann and Aulakh 2000), stages of crop growth, gas transport capability, type and amount of aerenchyma (Aulakh et al. 2000a; Butterbach-Bahl et al. 1997) also impart additional variability in CH_4 emissions. Rice plants provide methanogenic substrate through root exudates, help in transport of CH_4 and O_2 through aerenchyma and establishment of an active CH_4 oxidizing-site in the rhizosphere (Wassmann and Aulakh, 2000). Mitra et al. (2005) reported that decomposition of root exudates is one of the causes of CH_4 emission from rice soil. However, the rates of CH_4 production vary with soil types and CH_4 production is positively correlated with degree of aeration in the field. Redox potential of soil is one of the major factors that influence methane production and gas exchange capacity in the rice field (Kludze et al. 1993; Fig. 3.2).

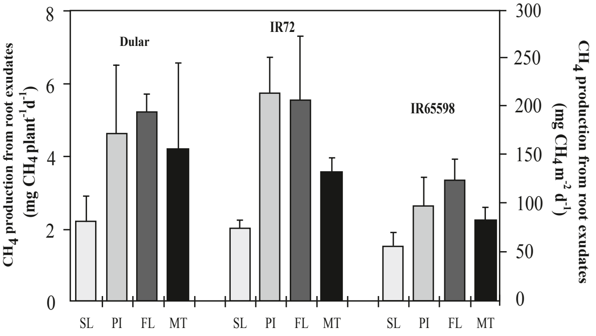

Fig. 3.3 Methane production potential of one-day exudates of Dular, IR72 and IR65598 cultivars at seedling stage (SL), panicle initiation (PI), flowering (FL) and maturity (MT). (Source: Aulakh et al. 2001)

Their study suggested that CH_4 emission was more strongly related to total organic C (r=0.920) than that of organic acids (r= 0.868). Rice root exudates act as a substrate for the methanogenic bacteria in anoxic condition. The study also suggested that for cultivation of high-yielding varieties (e.g., IR65598, IR65600) could reduce CH_4 emissions as they produce lowest exudate-induced CH_4 production. Thus, selection of rice cultivars could reduce CH_4 emission in regional and global level.

Various studies have reported about increment of root exudation due to lower membrane permeability and root porosity caused by P deficiency (Ratnayake et al. 1978; Graham et al. 1981; Lipton et al. 1987; Kirk and Du 1997). Low P could stimulate the downward transfer of oxygen and upward transfer of methane due to increased root porosity (Justine and Armstrong 1987; Kludze et al. 1993). P deficiency stimulates a chain of reactions that affect the partitioning of photosynthates and lead to higher root/shoot ratio (Marschner 1996; Kirk and Du 1997). Lu et al. (1999) reported that low P supply to rice plants resulted in significant increase in CH_4 emissions (34–50 micromoles under P deficiency and 10–22 micromoles under ample P supply), increase of root/shoot ratio by factors of 1.4–1.9, better development of root aerenchyma and increase in root exudation by factors of 1.3–1.8.

8.7 Methane Transport Capacity

Aulakh et al. (2000a) have studied methane transport capacity (MTC) of rice plants. They have reported that up to the concentration level of 7500 ppm, methane transport by rice plant increases linearly with increasing CH_4 concentration in the nutrient culture solution surrounding the roots. Their study also reported that MTC of IR72 was lowest at seedling stage (average 8 mg $CH_4/plant^{-1}/day^{-1}$), then increases gradually until panicle initiation (maximum, 120 mg $CH_4/plant^{-1}/day^{-1}$) and after that it gets reduced significantly at maturity (Fig. 3.3).

Thus, cultivation of rice varieties having low MTC can reduce methane emissions from rice fields (Butterbach-Bahl et al. 1997). Aulakh et al. (2000b) estimated

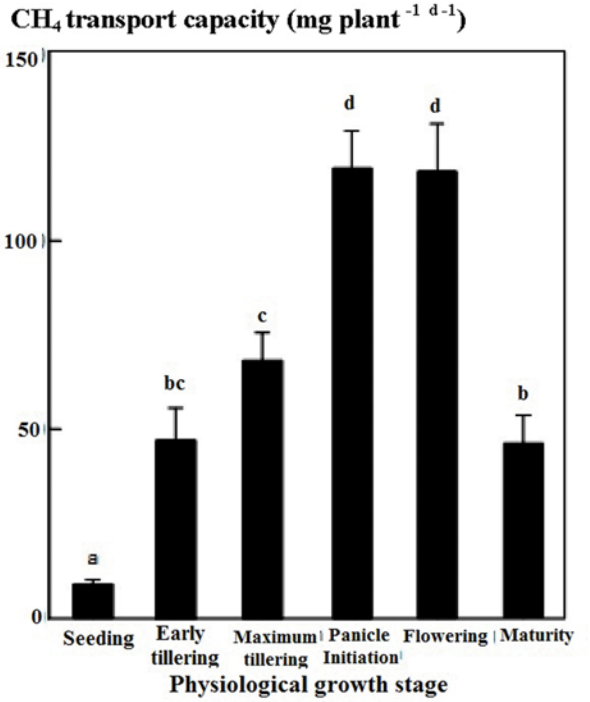

Fig. 3.4 Methane transport capacity of rice plants of cultivar IR72 at seedling, early tillering, maximum tillering, panicle initiation, flowering and maturity. Data shown is means ± SD of three replicate plants each measured in triplicate. Different letters indicate significant differences ($p > 0.05$). (Source: Aulakh et al. 2000a)

the MTC of four high-yielding varieties (IR72 > IR52 > IR64 > PSBRc 20) by using automated system.

Aulakh et al. (2002) studied the MTC of 18 inbred varieties and four hybrids at various growth stages. MTC of different varieties varied from 62 to 445 % of IR72-MTC. The study showed that tiller numbers were linearly co-related to MTC i.e., number of tillers directly determines CH_4 transport. Their study proved that the use of high-yielding cultivars with low MTC (e.g., KDML 105, IR65598 and PR 108) could be a viable option for reducing CH_4 emissions from rice fields (Fig. 3.4).

Nouchi et al. (1994) used modified diffusion model for quantitative estimation of methane transport through the micropores in the leaf sheath and the gaps at the joint of nodal plate and leaf sheath of the rice plants (Nouchi et al. 1990). Methane emission is mainly driven by CH_4 concentration gradient between atmosphere and soil pore water, molecular diffusion (Denier Van der Gon and Breemen 1993) and thermo-osmosis (Schröder et al. 1996).

Yao et al. (2000) reported that CH_4 emissions through rice plants are influenced by many factors like growth stage, rice cultivars, stem inter-cellar volume, length of root bundle and total root volume at matured stage. They studied CH_4 conductance among 11 different rice cultivars and reported that the CH_4 conductance is positively correlated with inter-cellar volume at tillering stage and root volume at the reproduction stage. They have also done regression analysis to prove that in both the stage of growth considered together, CH_4 conductance is significantly correlated

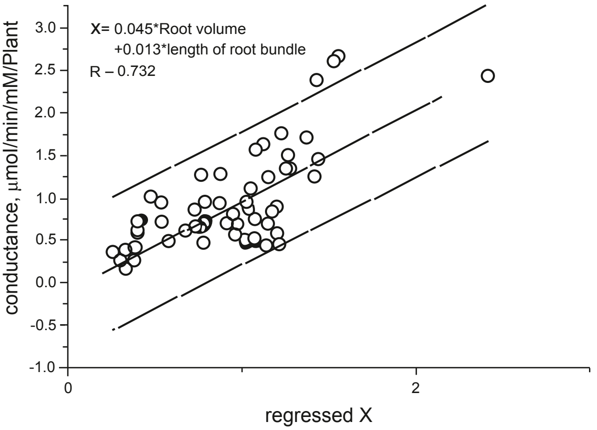

Fig. 3.5 Results of multi-dimensional regression analysis between plant conductance for methane and physical parameters; Regressed value R = 0.793 ($p < 0.01$). (Source: Yao et al. 2000)

with root volume (Fig. 3.5). Jones (1992) reported that the size of the micro-pores, the size of the inter-cellular space and plant conductance are proportional to the size of the rice plant.

9 Conclusion

The agricultural sector contributed 47 % of total CH_4 emissions in the year 2005 (IPCC-AR4 2007) and South and East Asia was the major contributor (82 % of total CH_4 emissions) because of widespread rice cultivation in the region. Many agricultural scientists, who have carried out various studies, recommended various measures for reducing CH_4 emission from the rice fields. CH_4 emission from rice fields is strongly influenced by existing water regime, local crop management practices, cropping rotation and quality of organic inputs used. Practice of no tillage system and cultivation of perennial crops can significantly reduce CH_4 emissions from soil by increasing soil C storage. In upland farming, direct seeded rice cultivation and ‘No Tillage’ system are two promising options for reducing methane emissions from cultivated rice fields. Use of prilled urea, urea-super-granule, and application of nitrification inhibitor (Nimin) can reduce CH_4 emissions effectively. Management of organic matter, application of organic matter during off-season drained period, application of biogas-slurry to the rice fields are some of the variants of measures to reduce GWP of rice soil. P deficiency in rice soil leads to increase in root exudates amount by lowering the membrane permeability and enhancement of downward transfer of O_2 and upward transport of CH_4, thus management of Phosphorous (P) availability in rice soil would be a viable option for reducing CH_4 emission.

Emission of CH_4 through the rice plants is influenced by various properties of the plant itself, i.e., photosynthate allocation capacity, root volume, oxidase activity in the vicinity of root tip, amount and nature of root exudates, properties of aerenchyma tissue, number and structure of nodes, stages of crop growth and methane transport capacity (MTC) etc.,. Various cultivars like Ranjit, IR 65598, IR 72, Koshihikari, Pusa 169, IR 65600, KDML 105, PR-108 emit far less CH_4 than that of other traditional varieties due to some variety-specific properties. Improved cultivar 'Ranjit' emits less CH_4 than 'Agni' due its better photosynthate allocation capacity, high-yielding varieties like Pusa 169, Pusa basmati, Pusa 677 emit less methane due to lower root exudation and low MTC.

Thus cultivar improvement in the line of developing new high-yielding varieties having low MTC, lower methane emission through aerenchyma and nodes, low amount of root exudates, can give the breakthrough in agricultural research system for reducing CH_4 emission from rice fields on a regional and global level without hampering the productivity.

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