ESTIMATION OF METHANE EMISSIONS FROM IRRIGATED BORO RICE AND ASSESSMENT OF POSSIBLE MITIGATION MEASURES

BY

MD. REAZ UDDIN KHAN

MASTER OF SCIENCE IN WATER RESOURCES DEVELOPMENT

INSTITUTE OF WATER AND FLOOD MANAGEMENT

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

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INSTITUTE OF WATER AND FLOOD MANAGEMENT

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Md. Reaz Uddin Khan
Roll No. M1009282002F
Session: October, 2009

This thesis is dedicated to my honorable
Parents, my sister and beloved Dinar

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ABSTRACT

Among the GHGs, methane is the leading heat trapper and acts as an effective contributor to global warming mechanism. Rice cultivation under continuously irrigated condition is the prime source of methane emission to the atmosphere. As the fourth largest rice producing country in the world, the present emission status of Bangladesh from irrigated Boro rice and applicability of different mitigation approaches is a contemporary concern. In this study an attempt was made to identify the current rate of emission, study the influence of agro-climatic factors on the emission rate and feasibility of mitigation measures. The study was carried out in three villages of Gazipur Sadar Upazilla of Gazipur district. Assessment of country's present rate of methane emission from 2000 to 2009 was estimated through the methodology proposed by IPCC (2006) and also by using CH4MOD2.5 model (Huang et al., 2004). Calculation was made for Aman (BR 11) rice variety and Boro (BRRI dhan 28 and BRRI dhan 29) rice varieties seasons. CH4MOD2.5 model was also used to analyze the effects of different agro-climatic factors on the rate of emission and forecast the future (in 2030 and 2050) emissions under SRES A1B emission scenario. Three FGDs were conducted with the farmers along with KII to assess the adaptability of the possible mitigation measures.

The results of the study show that by using IPCC methods, country emits 1071 Gg (Gigagram) of methane annually from both seasons. From CH4MOD2.5 model, it was estimated as 464 Gg of which 83% came from Boro and 17% from Aman rice. Cultivar specific emissions for BR 11, BRRI dhan 28 and BRRI dhan 29 were 20.4, 69.92 and 96.73 mg m^{-2} d^{-1}, respectively. Changing of both temperature and CO_2, increased the emission by 13% and 16% for BRRI dhan 28 and BRRI dhan 29, respectively, due to the availability of readily decomposable organic C. Increasing of 10 kg/ha of N_2 fertilizer had both effect on the emission rate. Sandy soil emitted more methane than clayey soil because of higher cohesive force in clay soil, which retained more water in the pore space. Higher emission was also estimated from rice straw incorporated fields. Around 27% of higher emission rate was estimated in BRRI dhan 29 due to higher plant height, growth duration and yield compared to BRRI dhan 28. Methane emission can be reduced by 71%, 80%, 87% and 93% by applying 3, 4, 5 and 6 IDWR (Intermittent Drainage Water Regime), respectively instead of CFWR (Continuously Flooded Water Regime). Instead of transplanting, direct seeding with 6 AID (Alternate Irrigation and Drainage) reduces emission by 94%. Shifting of 7 days and 14 days EFTP (Earlier from the Traditional Practice) reduced emission by 6% and 19% respectively from BRRI dhan 28, and 9% and 18% respectively from BRRI dhan 29. In the year 2030 and 2050, country will emit around 653 Gg and 906 Gg of methane from Boro rice (an increase of 39% and 56% respectively under A1B scenario) under CFWR. Incorporation of 3 and 5 additional drainages instead of CFWR, emission rate will be reduced around 64% and 84% for both the year 2030 and 2050. From the FGD, it was found that changing of rice cultivars is only applicable when framers are given a variety with higher yield, lower crop duration, moderate plant height and lesser tiller number. By using pellet urea and LCC, farmers used 18% less N_2 fertilizer. AWD is already practiced but uncertainty of electric supply, non-availability of irrigation water and low conveyance efficiency are the major difficulties to its adoption. Time and money consuming weed management is an obstacle to direct seeding. Due to fewer livestock, lesser amount of FM is already applied in the rice fields. Shifting of transplanting date is only applicable for high lands. As the study was carried out in one hydrological zone with A1B scenario, further studies in other zones and scenarios are needed for a better understanding of the emission rates and adoptability of the mitigation options.

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ABBREVIATION

AEZ	Agro-ecological Zone
AID	Alternate Irrigation and Drainage
AWD	Alternate Wetting Drying
BADC	Bangladesh Agricultural Development Corporation
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
BRRI	Bangladesh Rice Research Institute
CCC	Climate Change Cell
CFWR	Continuously Flooded Water Regime
DAE	Department of Agricultural Extension
DAS	Days After Seeding
DTWs	Deep Tube Wells
EFTP	Earlier from the Traditional Practice
FGD	Focus Group Discussion
FM	Farm Manure
FYM	Farm Yard Manure
Gg	Gigagram
GHG	Greenhouse Gas
GIS	Geographic Information System
GWP	Global Warming Potential
HI	Harvest Index
IDWR	Intermittent Drainage Water Regime
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
KII	Key Informants Interview
LCC	Leaf Color Chart
LLPs	Low Lift Pumps
MVs	Modified Varieties
OM	Organic Matter
PRECIS	Providing Regional Climates for Impacts Studies

PRRI	Philippine Rice Research Institute
RADMs	Readily Available Decomposable Materials
SRES	Special Report on Emissions Scenarios
STWs	Shallow Tube Wells
Tg	Teragram
US-EPA	United States Environmental Protection Agency

Chapter 1

INTRODUCTION

1.1 Background of the Study

Methane is the most effective greenhouse gas (GHG) in the earth's atmosphere after CO_2, contributing around 20% of global warming effects from the anthropogenic sources over the last century (IPCC, 2001). Among the other GHGs like carbon dioxide, nitrous oxide, chlorofluorocarbons, methane has a strong infrared absorption band, which traps the outgoing long wave radiation (especially the thermal radiation) from earth's surface (Wuebbles and Hayhoe, 2002). The efficiency of methane in trapping heat is 30 times more than that of atmospheric CO_2 (RAmanathan et al., 1985). In the year 2000, the concentration of methane in the atmosphere was estimated as 1.75 parts per million volume (ppmV), and due to human activities, the rate of methane emission is increasing at the rate of 1% per year (Purkait et al., 2007). If the GHG emission is continuing at the present rate, it is projected that the global average temperature will increase by about 1 °C by the year 2025 and by 3 °C by the end of the century (IPCC, 2001). Thus methane is significant contributor to concurrent global climate change.

Rice fields are a significant source of atmospheric methane via anthropogenic activities, emitting around 31112 Tg (Teragram) of methane globally (Denman et al., 2007). Most of the rice (around 57% globally), is grown in irrigated or continuous flooded fields under extremely anaerobic condition and this anoxic condition (i.e. absence of atmospheric O_2) in the rice fields stimulates the methane production and emission processes. Thus methane emissions from continuous flooded or irrigated rice fields is a net consequence of methane production in the soil by methane producing bacteria (methanogens), methane oxidation within oxic zones of the soil and flood water by methane oxidizing bacteria (methanotrops) and vertical transport of the gas from soil to the atmosphere (Xie et al., 2010). As, methane is the final product of several anaerobic microbial degradation of organic matter (OM), so rice plants via root exudation, plant litter, organic manure and residues from preceding crop are the primary sources of OM. Atmospheric temperature and CO_2, pH, organic amendment, chemical and organic fertilizer, soil redox potential, soil texture, water regime and rice cultivars are the major agro-climatic factors influencing the rate of methane emission from paddy fields. It has already been proved that, atmospheric concentration of CO_2 is increasing over the last few decades, increasing the global atmospheric temperature by trapping the thermal radiation from the earth surface. So, among the several agro-climatic factors affecting the rate of methane emission from rice fields, atmospheric temperature and CO_2 are the most concerning factors in the recent era. Because, many studies have demonstrated that, elevated concentration of CO_2 positively affects soil microbial C and elevated atmospheric temperature accelerates the turnover rates of soil organic C during the middle and later parts of the rice growing season (Li et al., 2004).

Rice is a staple food for more than half of the world's population. Various studies suggest that, the world's rice production must rise from the present 520 million tons to at least 880 million tons by expanding harvested area by 70% within 2025 to meet the demand of the exploding human population (Dubey, 2001). As rice is an important contributor to enhance global warming through extensive cultivation, country specific contribution to global methane emission from paddy fields and reduction of methane emission without affecting the yields under the current circumstances becomes a global concern.

Bangladesh is one of the most important (fourth largest) rice producing countries, containing 7.04% of the total world rice area (IRRI, 2009). To ensure food security for country's vast population (about 160 million) and coping with frequency of uncertain climatic event (drought and prolonged flood), the country is now expanding its irrigated rice area. Out of 8.21 million ha of net cultivable area, 5.13 million ha was irrigated in 2008-2009 (BADC, 2009).

Estimation of methane emissions from rice fields have been carried out for several countries (China, India, Indonesia, Thailand, Philippines) co-ordinated by IRRI (Neue and Sass, 1998). Depending on the methods used for estimation, the emission rate may vary in the same rice fields or within a country. Using the guidelines governed by IPCC 2006, Yan et al. (2009) estimated the annual methane emission from irrigated rice fields of major rice producing countries like China, India, Bangladesh, Indonesia and Thailand as 7.41, 3.99, 0.47, 1.28, and 0.18 Tg respectively. But by using a different methodology (use of GIS tools and model), Matthews et al. (2000) estimated the emission from irrigated rice fields of China, India, Indonesia, Philippines and Thailand as 3.73, 2.14, 1.65, 0.14 and 0.18 Tg CH_4 yr^{-1} respectively. In IPCC methodology, estimation rate was more or less double compared to estimation carried out by using GIS. Estimation by using country specific tools or techniques is more suitable than the methods which have been prescribed for the whole world. Model based estimation is also important to find out the effects of several factors on methane emission.

In the context of Bangladesh, methane emission from different water management regimes (Upland, Irrigated and Rainfed rice) were assessed as 767 Gg (Gigagram) in 1990 by US Environmental Protection Agency (Scheele, 2002). Whereas, for the same year, for flooded rice cultivation, the median estimated value was 439 Gg (Ahmed et al., 1996). Both the studies were based on the IPCC methodology. With the expanding of irrigated area, those emission rates are not valid now. But, there is no estimate of the current volume of methane emission and the possible strategies for reducing emissions. So, in the present study attempts were made to estimate the methane emissions from irrigated rice fields, identify the factors that could influence the rate of emission and assess the possible mitigation measures which would reduce the contribution of methane emission as well as harmonize the rice cultivation process.

1.2 Objectives of the Study

The study was conducted to fulfill the following objectives:

(i) To estimate the present status of methane emissions from irrigated Boro and rainfed Aman rice.

(ii) To identify the influence of agro-climatic factors on the rate of methane emissions.

(iii) To determine the farmers' perception regarding the methane emission mitigation measures.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Under the existing scenario of global climate change, actual estimation of greenhouse gas inventory from specific sector and country as well as taking initiatives to mitigate those sources is a contemporary issue. Methane has higher Global Warming Potential (GWP) than the other atmospheric gases. Rice fields are the key source of methane emission. But, it depends on some agro-climatic factors and country specific management practices. Due to increased concern about global food security, it is not possible to stop or reduce rice cultivation. Exclusive research is required to identify the effective mitigation measures of methane emission from rice fields without affecting or reducing the yields. From that perspective, a number of literatures were extensively reviewed so as assess the present status of methane emission and mitigation measures.

2.2 Mechanism of Methane Production and Pathway from Irrigated Rice Fields

Methane is produced in the anoxic (without O_2) layers of paddy soils as a result of bacterial (methanogenic) decomposition of organic matter (Dubey, 2001). Carbon is the basic compound for the activities of methanogenic fermentation which principally comes from three major sources such as the death of roots tissues from crops, the decay of both freshly added OM and humus and carbohydrate exudates from living root tissue (Sandin, 2005). Methane is produced from rice fields by a complete mineralization of OM in anaerobic environment after the sequential reduction of O_2, nitrates, manganese, iron and sulphate, which serve a electron acceptors for oxidization of OM to CO_2 (Yao et al., 1999; Mer and Roger, 2001). From the successive microbial decomposition of OM (CH_2O), H_2, CO_2 and acetate (CH_3COO^-) are formed (Mer and Roger, 2001). Wassmann et al. (2000) observed that, methanogenic bacteria can produce methane from both H_2 and CO_2 or acetate by using the following equations.

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad (2.1)$$

Or,

$CH_3COO^- + H^+ \rightarrow CO_2 + CH_4$ (2.2)

The whole process can be summarized by the following equation:

$2(CH_2O) \rightarrow CO_2 + CH_4$ (2.3)

Anaerobic degradation of OM involves four distinct successive processes including Hydrolysis, Acidogenesis, Acetogenesis and Methanogenesis (Mer and Roger, 2001; Yao and Conrad, 2001). Methane formation process and the pathway through which produced methane is emitted from the soil to the atmosphere is shown in the Figure 2.1.

- In hydrolysis, biological polymers are hydrolyzed into monomers (glucides, fatty acids, amino acids) by a hydrolytic micro flora that can be either aerobic or facultative or strictly anaerobic.
- In acidogenesis, monomeric compounds and intermediary compounds are formed during fermentation (production of volatile fatty acids, organic acids, alcohols, H_2 and CO_2) by a fermentative micro flora that can be either facultative or strictly anaerobic.
- Acetogenesis from the previous metabolites by a syntrophic or homoacetogenic micro flora.
- Methane formation from H_2/CO_2, acetate, simple methylated compounds or alcohols and CO_2 by methanogenic bacteria is in strictly anaerobic condition and constitutes the last step of methanogenic fermentation.

The transportation of methane from soil to the atmosphere is carried by three different pathways including transport through plants, ebullition and diffusion (Holzapfel-Pschornet et al., 1986).

Ebullition (gas transport via gas bubbles) is the common and significant mechanism of CH_4 flux in the natural wetland (Wassmann and Martius, 1997) and can play a vital role to transport methane under a high OM (Sass et al., 2000). It forms bubbles when the fermentation is emitted through water (Sandin, 2005). At the very beginning of plant's life cycle (transplanting and vegetative stage), when rice plants are not well developed to transfer CH_4, bubble formation and vertical movement in the bulk of the soil is the main transfer mechanism of CH_4 but it is only about 10% of the total emission during a plant's emitting cycle (Byrenes et al., 1995; Mer and Roger, 2001). However, it occurs only at the surface layer and its rate is regulated by CH_4 concentration, temperature and soil porosity (Li, 2000).

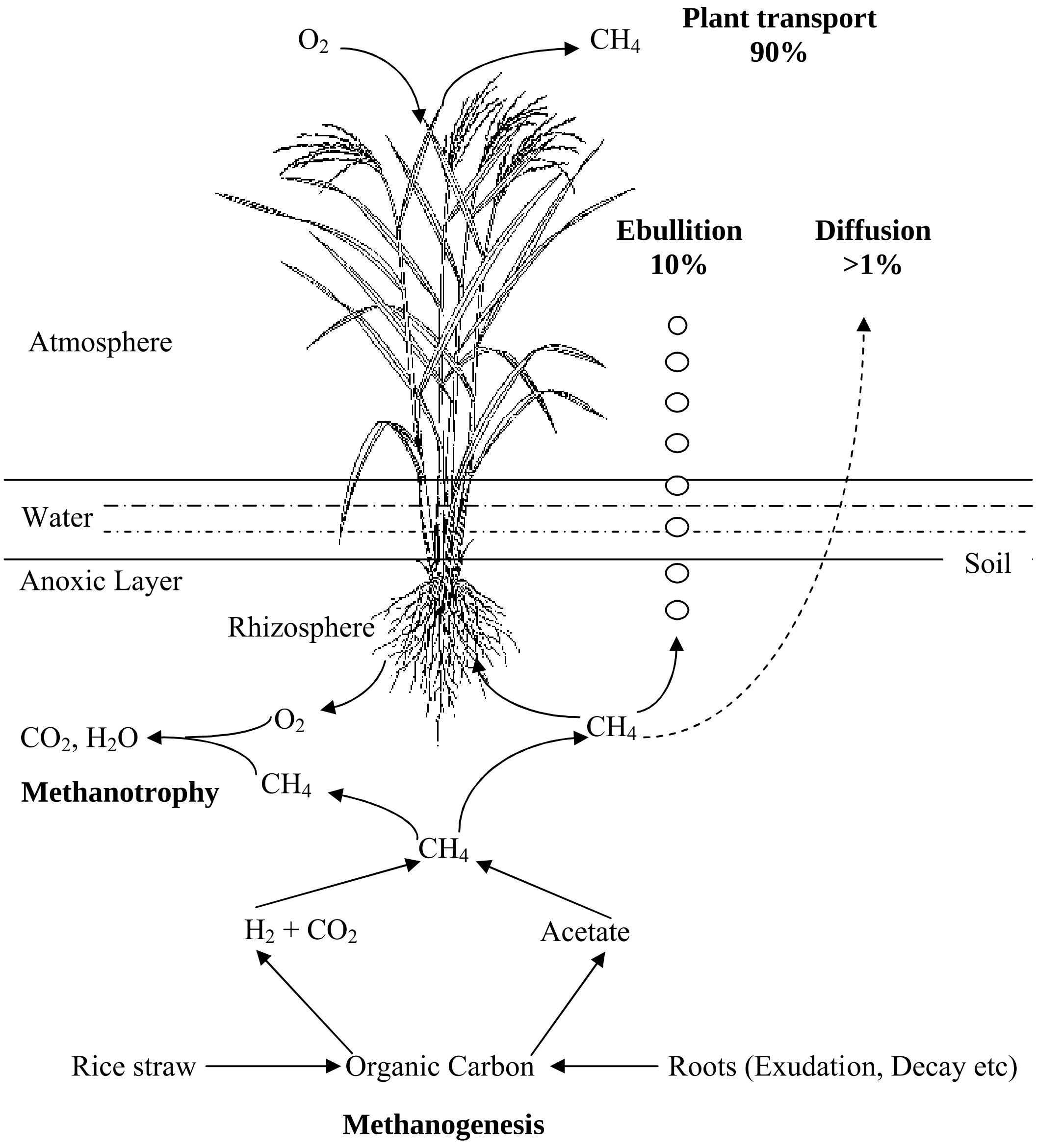

Figure 2.1: Conceptual diagram of methane production and emission pathway from rice plants and soil (Holzapfel-Pschornet et al., 1986).

Diffusion of methane from paddy soil is the function of surface water concentration of CH_4, wind speed and CH_4 supply to the surface water (Sebacher et al., 1983). It is a very slow process because the diffusion rate of gaseous CH_4 is very slow in liquid phase and thus contributes a tiny portion (around <1%) of total emission (Schutz et al., 1989; Aulakh et al., 2001).

Among the three different CH_4 transport path ways, plant mediated transport is the primary mechanism for methane transport from soil to the atmosphere and contribute around 90% of total methane emission (Schutz et al., 1989; Tyler et al., 1997; Wassmann et al., 2000). At the reproductive stage, when CH_4 production rate is high in the soil, Wassmann et al. (2000) measured that, dominant portion of produced methane emitted in this stage is through the aerenchyma of rice plant. In the plant aerenchyma, CH_4 is emitted through the micro pores in the leaf sheath of the lower leaf position, the stomata in the leaf blades, culm and roots (Nouchi et al., 1990; Sandin, 2005). So, the structure and formation of plant's aerenchyma as well as the porosity of roots are the basic function that affects the emission rate of methane through this process.

2.3 Effects of Agro-climatic Factors on the Rate of Methane Emission

Methane production, oxidation and emission from the irrigated rice fields are affected by some agro-climatic factors. Studies were accomplished to find out the most influential factors those considerably affect the rate of methane emission from irrigated rice fields. The findings of those reports suggest that, the most important factors that significantly affects the rate of methane emission from rice fields includes temperature, rice cultivars, soil type, soil redox potential, soil pH, water regime or water management practice, application of fertilizer (both chemical and organic) and organic matter incorporation (Wassmann et al., 2002; Huang et al., 2002; Kruger and Frenzel, 2003; Ma et al., 2008). Multiple authors have established a positive correlation between the atmospheric concentrations of CO_2 and methane emission (Ziska et al., 1997; Sakai et al., 2001; Kim et al., 2001, 2003).

2.3.1 Effects of temperature

Atmospheric temperature is one of the most important agro-climatic factors in the era of global warming which affect interannual variation in CH_4 emissions (Watanabe et al., 2005). Over the last few decades, both the maximum and minimum temperature has increased. The instrumental temperature record shows that the average global temperature has increased by 0.74 °C during the 20th century (IPCC, 2007). Solomon et al. (2007) explained in their studies that, during the 21st century the global temperature are likely to rise a further 1.5 to 1.9 °C for lowest emissions scenario and 3.4 to 6.1 °C for their highest emission scenario.

According to Schrope et al. (1999), the elevated atmospheric temperature especially at > 35 °C (Allen et al., 1994) with elevated concentration of CO_2 stimulated the plant productivity and methanogenic activity which leads to higher methane emissions from rice fields. Increasing temperature may lead to increase in the total seasonal daytime uptake of CO_2 at both levels (i.e. both the above-ground and below ground components of rice plants) of CO_2 exposure (Allen et al., 2003). Another study carried out by Snyder (2000) has shown that, with the increasing of temperature, the nonstructural carbohydrates and N in culms increased concurrently which furthermore increased photoassimilation available for translocation to roots and stimulated CH_4 production by potentially providing more exudation. In the other way it can be said that, elevated atmospheric temperature modified the aerenchymal system of rice plants in such a way that it will support more rapid gaseous (methane) diffusion and emissions of CH_4 (Watanabe and Kimura, 1998). Wassmann et al. (1998) observed that at temperature between 25 and 35 °C, development of CH_4 production and rate of emission become faster. However, only the effect of elevated temperature is not significant enough to enhance the methane emission rate from flooded rice practice. Elevated temperature with elevated atmospheric CO_2 significantly increase the rate of methane emission from irrigated rice fields because higher the rate of temperature increase the faster is the rate of microbial degradation of organic matter (PRRI, 2011).

Yang and Chang (1998) demonstrated a positive correlation between total methane production and incubation temperature. Like atmospheric temperature, there is some optimum soil temperature through which CH_4 production is stimulated. Studies from Singh et al. (2003) found that, methane emission rate reached the peak in the afternoon i.e. 2 of 3h after mid day and during these hours soil temperature reached the highest value. The study concluded that, if all the factors are constant, methane emission from paddy soil is a soil temperature dependent process.

2.3.2 Effects of atmospheric CO_2

Methane produced in the flooded rice fields and its quantity primarily depends on the availability of methanogenic substrates which principally originates from both the soil organic matter i.e. incorporated organic matter or rice straw and root exudates or root autolysis products (Cheng et al., 2006). Various studies found a significant correlation between elevated atmospheric CO_2 and the rate of methane production. Elevated CO_2 positively affects the rice biomass production (below and above the ground) and grain yield (Sakai et al., 2001; Kim et al., 2001, 2003) and accelerates the decomposition rates of soil organic C (e.g. carbohydrates) during the middle and later parts of the rice growing season (Cheng et al., 2001; Hoque et al., 2001; Li et al., 2004). The supplementary biomass produces more root exudates and the greater number of tillers results in more surface area for methane emission into the atmosphere (Inubushi et al., 2003).

Recent studies have demonstrated that, with 60-100% increase of atmospheric CO_2 above the ambient level, methane emission is stimulated from rice fields by 19-300% in temperate (Cheng et al., 2006) and tropical regions (Allen et al., 2003) and thus intensify the global warming effects. On the other hand, methane emission from temperate to sub-tropic paddy fields is stimulated by 38-188% when the concentration of CO_2 increases up to 60% (Inubushi et al., 2003; Xu et al., 2004; Zheng et al., 2006). Moreover, the combined effects of both elevated atmospheric temperature and CO_2 on the rate emission is more influential rather than the effects of elevation of CO_2 only.

2.3.3 Effects of rice growth stage

Methane emission varied with growing stage of rice plant. Lower emission was observed at the earlier stage of rice plant i.e. vegetative stage due to lower level of methanogenesis (due to unavailability of organic C) and poor conduction of CH_4 from the soil to atmosphere. However, higher emission was observed at the later stages of vegetative, reproductive and ripening due to the presence of metabolizable organic C in the form of root ecudates and impact of photosynthetic activity and anaerobic degradation of indigenous organic C of soil (Setyanto et al., 2004).

2.3.4 Effects of rice cultivar

Rice cultivar is one of the dominant agricultural factors which actively control the production, oxidation and emission of methane from flooded rice cultivation. Studies show that, there have three different ways through which rice cultivar affect methane production from rice fields. First, they influence the production of root exudates and sloughted-off tissues which stimulates the methanogenesis process. Second, rice cultivars itself act as an active CH_4 oxidizing site in rhizosphere by supporting O_2 counter transport through aeranchyma system. Third, they act as conduits for gas exchange and through the aeranchyma system around 90% of CH_4 transported and released into the atmosphere from paddy soils (Jia et al., 2002). Several studies have conducted to identify the correlation of rice cultivars with methane emission. The research findings have suggested that, the variation of methane emission from rice fields is due to the variation of physiological traits such as CH_4 transport capacity, patterns of roots exudates, duration of growth, grain yields, number of tillers, dry weight of aboveground biomass, etc of rice cultivars.

The O_2 transport capacity of all the rice cultivars is not same because of difference in aeranchyma system. So, the difference of downward transport of O_2 in different rice cultivars is an important trait for the difference of CH_4 emission. Roots exudates are the key source for the methanogenesis process. The rice cultivar which contains more roots exudates i.e. carbohydrates, with higher readily available decomposable organic matter, emit more methane to the atmosphere (Setyanto et al., 2004).

Setyanto et al. (2004) also showed that, among the two important physiological traits of rice cultivars (duration of plant growth and grains yields), duration of plant growth is the dominant for regulating the rate of methane emission. Longer growth period with higher grain yield significantly stimulated the emission rate of methane. Plant mediated CH_4 transport widely varied with different rice cultivars while higher tiller maximize the CH_4 flux from soil to atmosphere (Aulakh et al., 2000).

2.3.5 Effects of application of nitrogen fertilizer

The basic reason for applying nitrogen fertilizers into the rice fields is to achieve higher grain yields. On an average, N fertilizer is applied in the rice fields at the rate of around

27-151 kg N ha^{-1}. It has both the direct and indirect effects on the rate of methane emission. At the ecosystem level, application of N fertilizer and its effects on methane emission is the net consequence of few processes including CH_4 production, oxidation and transport from the soil to atmosphere (Cai et al., 2007). These effects could be either positive or negative impacts on the ecosystem at microbial and biochemical levels (Bodelier and Laanbroek, 2004; Zheng et al., 2006; Cai et al., 2007).

N fertilizer positively affects CH_4 emission by stimulating CH_4 production and vascular transport capacity via enhancing methanogenic activity and rice growth (Schimel, 2000; Xu et al., 2004). On the other hand, the negative effect of application of N fertilizer on CH_4 emission is mainly attributed to the stimulation on CH_4 oxidation via enhancing the activity of methanotrops (Kruger and Frenzel, 2003; Bodelier and Laanbroek, 2004). Due to the counter balance among various effects, it is difficult to identify the net effects of N fertilizer on the methane emission. In rice cultivation, the most widely used form of N fertilizer is urea which is ammonium based and is readily hydrolyzed into water after its application to rice fields. In the farmer's fields, urea can stimulate the length of plant growth and thus increases the CH_4 flux. Similarly, it can also stimulate CH_4 oxidation and thus reduces the CH_4 flux. Xie et al. (2010) have showed that, the application of ammonium based fertilizers at a moderate level (150 kg N ha^{-1}) significantly enhanced rice aboveground biomass by around 57% compared to the condition of no fertilizer application. Increasing of application rate from moderate to high level (250 kg N ha^{-1}), further enhanced rice aboveground biomass by about 13%.

If soil pH is increased then methane production is reduced, especially when the fertilizer is deeply incorporated into the soils (Yang and Chang, 1998). The pH range of 6.5-7.5 is favorable for the growth of methanogenic bacteria, while the optimum range of pH for methane emission from paddy soil is around 6.7-7.1 (Aulakh et al., 2001). Methane production is not stimulated when the soil pH become below the lower level as well as above the upper level. Application of urea to acidic soil is mostly favorable for methane production rather than that of alkaline soil. So, lower rate of urea application to the rice fields is not a worry worthy concern as it considerably mitigates the rate of methane emission.

2.3.6 Effects of water management practice

Methane emission from rice fields directly varies with different mode of water management practices i.e. water regime. Among the different rice cultivation and mode of water management, continuously flooded water regime is the most favorable for the production and emission of methane from rice fields. For stimulating the growth and activities of methanogenic bacteria, anaerobic condition into the rice fields is prerequisite. Plenty of readily available organic matter may not ensure the peak of methane emission from rice fields unless and until a certain depth of water is retaining in the fields throughout the whole growing period.

Various researches have found a significant correlation between soil microbial activity and the depth of water retained above the paddy fields. Water content increases the methanotropic activity up to the field capacity and subsequently increases the methanogenic activity when the water content exceeds the field capacity. Anaerobic condition of soil increases when the depth of irrigation ranging from 0 to 10 cm and stimulated the methane production and emission. On the other hand, percentage of methanotrophs decreases when the depth of water becomes > 10 cm (Yang and Chang, 1998). Because, at that depth, around 60-100% soil porosity is filled with water which hinders the transfer of methane gases from soil to the atmosphere.

2.3.7 Effects of organic amendment

Organic amendment is the principal substance for the production of methane from irrigated rice fields. In methane production mechanism, methanogenic bacteria decompose the complex from of organic amendments and breakdown it into simple from which is known as methane. So, methane production from paddy soil is directly dependent on the bulk of organic matter's availability. More the availability of OM in the paddy soils as well as favorable conditions for its decomposition, more and faster the rate of methane production from rice fields.

Various studies were carried out to find both the short and long term effects of application of various types OM into the different rice cultivation practices on methane emission. Although farm yard manure (FYM), urea, green manure, pig manure, residual decomposed OM stimulates the emission of methane from paddy soil, but the contribution of those are not as similar as rice straw (Yang and Chang, 1998). Estimating methane emission from five different paddy fields with five different rate of rice straw application, Naser et al. (2007) demonstrated that, among all the types of traditional practices of OM incorporation, rice straw dramatically increase the rate of methane emission and it also increase proportionately with the rate of application of rice straw. Rice straw containing field emit 243-1000% of methane compared to the rice fields containing no rice straw. The reason behind this could be the contents of cellulose, hemicelluloses, lignin, water soluble sugar and ether soluble lipid (Yang and Chang, 1998). That means, in rice straw, nonstructural organic C is more compared to other OM. Thus the decomposition rate is faster. Rice cultivars, in which growth is more, contain more roots and emit more methane.

2.3.8 Effects of soil texture

In the context of methane emission from submerged paddy soil, soil texture i.e. proportion of sand to clay is also a significant factor. This is because texture is involved in the establishment of the anaerobiosis needed for nethanogenesis, protecting organic matter from decomposition, transfer and trapping of methane produced in the reduced soil and affecting the depth of the oxidized soil layer hosting methanotrophs (Mer and Roger, 2001). The porosity of sandy soil is more than that of clay soil. High pore size means water holding capacity is low and thus they are filled with free oxygen. So, it seems that, methane emission is higher in clay soil as it is poorly drained and prone to anaerobiosis to favor methanogenesis. High clay content can also hinder the emission of methane, because in clay soil, cohesive force is more compared to sandy soil, which strengthen the water holding capacity and thus it traps the methane bubble beneath the upper layer of paddy soil and hindered the transfer of methane from soil to the atmosphere (Sass et al., 1994). That is why methane emission is higher in sandy soil rather than the clay soil.

2.4 Estimation of Methane Emission from Rice Fields

The estimation of methane emission from rice was first conducted by Koyama (1963). His study was based on laboratory incubation of paddy soils and estimated the global annual emission rate as 190 Tg CH_4. Few years later, in California, the first field measurements were carried out by Cicerone and Shetter (1981). In their study, they estimated the global annual rate of methane emission as 59 Tg. Holzapfel-Pschorn and Seiler (1986) conducted the first full season measurements from Italian rice fields and reported a higher average flux (16 mg CH_4 m^{-2} h^{-1}), which resulted in a larger global annual emission rate of 120 Tg. Based on exponential relationship between CH_4 flux and soil temperature, Schutz et al. (1989) observed an average CH_4 flux from Italian rice fields as 12 mg CH_4 m^{-2} h^{-1} and by using this value they derived global annual rate of CH_4 emission as 50-150 Tg with an average value of 100 Tg from rice fields. All of these studies were conducted by considering a limited number of hourly and daily fluxes and assessed that methane emission is more or less global rice area and temperature dependent. In 1990 Intergovernmental Panel on Climate Change (IPCC) developed a methodology and provided a value of annual global methane emission from rice fields in the ranges of 25-170 Tg CH_4 with an average value of 110 Tg CH_4. As methane emission is dependent on various agro-climatic factors, incorporating those factors, IPCC revised their methodology in 1996 and furthermore very recently in 2006. By using revised guidelines of 2006, global annual methane emission from rice fields was assessed as 25.6 Tg CH_4 (Yan et al., 2009). But still it has some debates because IPCC guidelines overestimate the emission value. For instance, by using IPCC guidelines of 2006, Yan et al. (2009) estimated that, the total annual methane emission from Chinese rice fields was 7.41 Tg CH_4. While by using climate-based GIS empirical model and the meteorological data, emission was estimated as 5.85 Tg CH_4 from the same rice fields (Kang et al., 2004). Similarly, Huang et al., 2004 developed a semi-empirical model (CH4MOD2.5) to better improve the estimation from China rice fields. So, to determine the exact scenario of methane emission, country specific methodology is required.

In Bangladesh, Ahmed et al. (1996) reported that the country's total methane emission from flooded rice fields in the year 1990 ranged between 257 Gg CH_4 (i.e. 0.26 Tg) and 622 Gg CH_4 (i.e. 0.62 Tg) with an average value of 439 Gg CH_4 (i.e. 0.44 Tg). The study followed the IPCC guidelines. By using the same methodology, United States Environmental Protection Agency reported that, in 1990 country's annual rate of methane emission was 767 Gg CH_4 (Scheele, 2002). The report also provided some projection of future CH_4 emission from rice fields for 1995 (730 Gg CH_4), 2000 (781 Gg CH_4), 2005 (850 Gg CH_4), 2010 (918 Gg CH_4), 2015 (977 Gg CH_4) and 2020 (1029

Gg CH_4). By using the IPCC revised guidelines for greenhouse gas inventory of 2006, Yan et al., (2009) reported that, annual rate of methane emission from all types of rice fields of Bangladesh as 1.66 Tg CH_4 (i.e. 1660 Gg CH_4) and from irrigated rice fields the value is 0.47 Tg CH_4 (i.e. 470 Gg CH_4).

2.5 Possible Mitigation Options of Methane Emissions from Rice Fields

As methane emission is the result of activity and growth of methanogenic bacteria under strictly anaerobic condition, change in agricultural management practices with an intention to alter the ideal condition for methane formation should be the basic strategy for any kind of mitigation option of methane from irrigated rice fields (Guo and Zhou, 2007). Thus, alternate wetting drying (AWD) or mid-season drainage could be the prime and effective mitigation option (Li et al., 2003; PRRI, 2011). AWD is a modern water saving technology (around 15-30%) and farmers can easily practice and manage it into their rice fields. With this practice, over the whole growth period, multiple aerations can take place. That means, AWD creates oxic condition into the rice soil for few days which suppressed the activities of methanogenesis (Corton et al., 2000) and thus reduce on an average 56-61% of methane (Singh et al., 2003). Although, after 3-5 days, when the irrigation is incorporated, the process of methane emission restart again but it cannot reach the peak as seen in the continuously flooded condition.

Various studies were carried out to identify the effects of aeration number on methane emission. Single aeration could reduce seasonal methane emission by 50% (Sass et al., 1992; Kimura, 1992) where as multiple aeration could significantly reduce by 88% of methane flux without affecting the yields (Sass et al., 1992; PRRI, 2011). Experiment results by the researcher shows that, applying intermittent irrigation over the continuous flooding could decrease 15% (Adhya et al., 2000) and 28% (Jain et al., 2000) of methane emission but in China the figure was observed as 30% (Lu et al., 2000). The disadvantages of this method are increased weeds during the non-flooded period and increased nitrous emission but these are negligible and can be managed easily (PRRI, 2011).

Use of low CH_4 emitting rice cultivars could be an option to mitigate methane emission from rice fields. Extensive research is needed to develop new plant type, where some morphological traits such as roots, biomass, number of plant tillers and dry matter weight of aboveground biomass should be considered. Rice cultivars which have minimum number of tillers (that may not affect the yields) but with higher proportion of productive tillers, is the strategy for developing new rice cultivar which can perform better in emission reduction context (Setyanto et al., 2004; PRRI, 2011).

Improved use of chemical fertilizer, especially the N fertilizer and use of another fertilizer as substitute of urea is a promising mitigation option (PRRI, 2011). Application of urea at the depth of soil can decrease the emission compared to incorporation in the surface of rice fields (Guo and Zhou, 2007). Using sulfate containing fertilizer like $(NH_4)_2SO_4$ (ammonium sulfate) instead of urea can reduce methane emission by 25-36% (Singh et al., 2003; Guo and Zhou, 2007). In this case, sulfate reducing bacteria compete with methanogens for H_2 and thus hindered the formation of CH_4 into the soil. Phosphogypsum applied in combination with urea reduce emission by more than 70% (Guo and Zhou, 2007; PRRI, 2011).

Direct seeding is a potential mitigation measure of methane due to having some attributes like, shorter flooding periods and crop maturity and decreased soil disturbances (PRRI, 2011). Study carried out by Corton et al. (2000) showed that, direct seeding can reduce around 16-54% emission when compared with transplanting. Direct seeding can be both in two forms such as direct seeding on dry soil and direct seeding on wet soil. In case of transplanting, duration of seedling is important. Ko and Kang (2000) reported that, in comparison with transplanting with 8 days old seedling, transplanting with 30 days old seedling, direct seeding on wet soil and direct seeding on dry soil reduced CH_4 emission by 5%, 13% and 37% respectively.

Change in types and mode of organic matter incorporation into the rice fields is a possible and effective mitigation option. Fresh rice straw is high in labile organic C which is treated as the source of methanogenesis substrates (Minoda and Kimura, 1996) and thus the incorporation of rice straw enhanced CH_4 emission by 16% but the use of fermented cowdung and leaf manures in continuously flooded condition reduced emission by 64% (PRRI, 2011) and 58% respectively (Singh et al., 2003). Moreover broadcasting of rice straw instead of incorporation into the soil reduce emission rate by 12% (Lu et al., 2000). Prasanna et al. (2002) reported that cyanobacteria can significantly reduce the emission of CH_4 by stimulating the activities of methanotrophs and act as O_2 provider in the paddy soil.

Change in some traditional agricultural practices can be the effective mitigation options. Among them, shifting of planting dates and adjustments with cropping calendar is one. Conventional tillage practices during the land preparation release the soil entrapped CH_4 of previous crop and enhanced soil C losses. In irrigated rice fields use of no tillage can significantly reduce the methane emission rate. But the problem is that, it has chance to attract harmful pest to unincorporated residue and favor to increase of weeds. In that case, applied integrated pest management could be an effective measure (PRRI, 2011). All of these mitigation strategies are not unique for all the rice fields and for all the locations. Based on the geographic location, available information, adequate knowledge and experience, measures could be changed from one rice field to another.

Chapter 3

METHODOLOGY

3.1 Introduction

The study has been carried out through three different phases. In the first phase, country's status of methane emission from rice fields over the decade (from 2000 to 2009), was estimated through the methodology proposed by IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) as well as by using CH4MOD2.5 model developed by Huang et al. (2004). IPCC methodology is more general, which means that some of the scaling factors for calculating the emission rate cannot handle the variability in climatic, soil and crop factors. As methane emission depends on various agro-climatic factors, there is no scope to consider these variabilities in IPCC governed methodology. In addition, some of the prerequisite condition to choose some scaling factors may not match with the actual field practice. But even under the aforementioned constraints, the IPCC methodology is well established method for green house gas inventory computation.

As an alternative to IPCC methodology, a number of models have been developed for the computation of methane emission. Among these models, CH4MOD2.5, this is developed in China but widely used in a number of countries (Xie et al., 2010). In the study, CH4MOD2.5 model was used which is capable of estimating the methane emission from rice fields considering regional agro-climatic and management factors. To run the model, some of the input parameters have been collected from primary sources and others from secondary sources.

In the second phase, how several agro-climatic factors (such as temperature, concentration of atmospheric CO_2, nitrogen fertilizer, soil texture, types of OM, rice cultivars and different water management practices etc.) influenced the rate of methane emission form irrigated Boro rice field were assessed by using the CH4MOD2.5 model. The future emission scenarios (for the years 2030 and 2050) from two mostly adopted Boro rice cultivars i.e. BRRI dhan 28 and BRRI dhan 29 were also evaluated by using the same model.

At the final stage, the contribution of different mitigation measures (such as adoption of AWD, different rice cultivars, change of application rate of nitrogen fertilizer and OM, direct seeding as a replacement of transplanting and shifting of transplanting date etc.) to reduce the rate of methane emission from irrigated Boro rice fields was quantified through the model. The farmers' perception regarding the possibility of adoption of these options was also investigated by carrying out Focus Group Discussion (FGD) and Key Informants Interview (KII) in the study area.

3.2 Calculation of Methane Emission form Rice Fields by Using IPCC Methodology

In this study, gross estimation of methane emission per year from rice fields (both the Aman and Boro rice) for the whole country was calculated by following the Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). Aus cultivation was not considered in the study because it is totally rainfed and the adoption rate is not as high as the Boro and Aman rice. Over the last few years aus rice showed a declining trend at the country. For instance, in the year 2007-08, the total area cultivated for Aman was about 48% and Boro was about 43%. But for aus the cultivated area was only about 8% (BBS, 2009). The computation was done for a particular decade from 2000 to 2009. The following equation was used for the calculation.

$$CH_{4\,\text{Rice}} = \sum_{i,j,k} (EF_{i,j,k} \times t_{i,j,k} \times A_{i,j,k} \times 10^{-6}) \qquad (3.1)$$

Where,

$CH_{4\,\text{Rice}}$ = Annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}

$EF_{i,j,k}$ = A daily emission factor for *i, j* and *k* conditions, kg CH_4 ha^{-1} day^{-1}

$t_{i,j,k}$ = Cultivation period of rice for *i, j* and *k* conditions, day

$A_{i,j,k}$ = Annual harvested area of rice for *i, j* and *k* conditions, ha yr^{-1}

i, j and k = Represent different ecosystems, water regimes, type and amount of organic amendments, and other condition under which CH_4 emissions from rice may vary.

For single cropping pattern, IPCC prescribed the value of harvested area i.e. $A_{i,j,k}$ will be the total of the cultivated area for that particular rice in a given year. In case of multiple cropping patterns at the same year, harvested area will be the sum of the total cultivated area for each crop. For a given year, the total cultivable land of Aman is not exactly equal to the total cultivable land of Boro. The total harvested area for both Aman and Boro were collected for a particular year and was considered as the annual harvested area for that particular year.

3.2.1 Calculation of daily emission factor

IPCC has prescribed another equation to calculate the daily emission factor for the Equation 3.1. Moreover, the calculation for the study condition was carried out by using the following equation.

$$EF_i = EF_c \times SF_w \times SF_p \times SF_o \times SF_{s,r} \tag{3.2}$$

Where,

EF_i = Adjusted daily emission factor for a particular harvested area.

EF_c = Baseline emission factor for continuously flooded fields without organic amendments.

SF_w = Scaling factor to account for the differences in water regimes during the cultivation period.

SF_p = Scaling factor to account for the differences in water regimes in the pre-season before the cultivation period.

SF_o = Scaling factor should vary for both type and amount of organic amendment applied.

$SF_{s,r}$ = Scaling factor for soil type, rice cultivar, etc., (Not yet available for IPCC source)

The scaling factor $SF_{s,r}$ for soil type and rice cultivar was not considered because IPCC has set up some default values of the concerned scaling factors except for $SF_{s,r}$.

3.2.2 Calculation of scaling factor for organic amendments

The scaling factor for organic amendments was calculated by using the following equation which is governed by IPCC.

$$SF_o = (1 + \sum_i ROA_i \times CFOA_i)^{0.59} \qquad (3.3)$$

Where,

ROA_i = Application rate of organic amendment, in dry weight for rice straw and fresh weight for others, ton ha^{-1}.

$CFOA_i$ = Conversion factor for organic amendment.

As farm manure, the retained rice biomass in the fields from previous crop was considered as OMs for the study. So, to calculate the scaling factor of both OMs, the equation has modified further. Information collected during FGD and KII was used to calculate both the rate of farm manure and rice straw incorporation into the farmer's fields for a particular rice cultivation period. A sample calculation for computing the rate of rice straw incorporation form BRRI dhan 29 is given in Appendix A.

3.3 Calculation of Methane Emission form Rice Fields by Using CH4MOD2.5 Model

The present level of methane emission from rice cultivation over the whole country was also estimated through CH4MOD2.5 model developed by Huang et al. (2004). It is the most widely validated computer simulated semi-empirical model, which simulates methane emissions from rice fields during the rice growing season under either ambient or elevated atmospheric concentration of CO_2 with multiple intermittent irrigations and drainages (Xie et al., 2010).

The model was developed on the basis of some assumption or hypothesis. The first hypothesis was methanogenic substrates are principally resulting from rice plants itself i.e. roots and exudates as well as the addition of OMs i.e. straw of previous crop that is retained in the fields after harvesting and incorporation of organic manure into the rice fields. Other hypothesis was methane produced in the soil enters the atmosphere via two basic pathways i.e. plant mediated transport and bubble ebullition, both of which are controlled by rice growth and development.

There are three distinguished and important features that made the model more practical and fields oriented. First of one is that, different water management practices like continuously irrigated or intermittent irrigation and drainage or any other, can be incorporated into the model. Thus the obtained results were most likely to be close to the real field observations. The second one is that, the model can simulate the effects of elevated concentration of atmospheric CO_2 which potentially stimulates the production, transportation and emission of methane from the rice fields. It is a significant feature as it can predict the future pattern of emission considering the concurrent and future climate change scenarios. The final one is that, the model can simulate the effects of incorporation of nitrogen fertilizer in the fields which is primarily used to enhance the growth rate of rice plants. The flow diagram for the conceptual structure of the CH4MOD2.5 model is given in the Figure 3.1. Screen shots of the input parameters and output of the model are given in Appendix B.

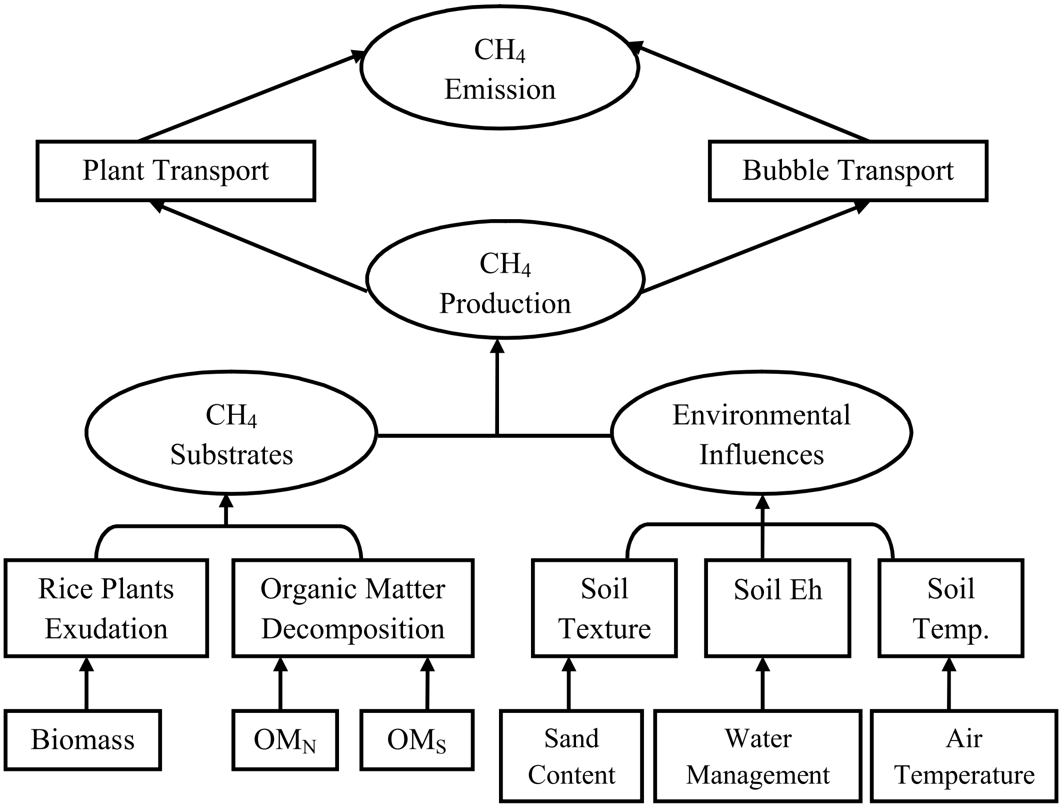

Figure 3.1: Conceptual structure of the CH4MOD2.5 model (Xie et al., 2010)

3.3.1 Input data for running the model

The model has three different interfaces for inputting the data regarding the general information, farming information and organic matter incorporation information. All of the data can be incorporated on the regional or country basis.

3.3.1.1 Parameter for general information

In the model, all the parameters for general information is classified into three different groups such as site general parameters, rice growth and soil texture. Through the incorporation of longitude and latitude data in the site general parameters, the model can be run for specific location, region or even the country. Changing of atmospheric concentration of CO_2 can also be added in this section. In the rice growth section, yield information about the rice cultivars for which the model will be performed, as well as information about the retained biomass i.e. rice straw of previous crop can also be added here. At the last section on soil texture, regional or country specific data about the soil pH and soil properties can be incorporated. Country or regional specific daily air temperature (both maximum and minimum) and daily average precipitation which are also important parameters, can be added in this part. All the model parameters regarding the general information are given in the Table 3.1.

Table 3.1: Model parameter for general information

Name of Input Parameter	
Site general parameters	Longitude, latitude and altitude (m)
	Atmospheric concentration of CO_2 ppm
Rice growth	Aboveground biomass on transplanting date (kg/ha)
	Grain Yield (kg/ha)
Soil texture	Soil pH
	Sand (0-1)
	Clay and Silt

3.3.1.2 Parameter for farming information

This segment consists of all the information regarding the transplanting and harvesting of rice plants. Date of transplanting and harvesting as well as flooding and drainage date for different farming practices can be incorporated here. Multiple numbers of irrigation and drainage can be supplemented in this part which is important for the methane emission and production context. Water depth for certain irrigation and the application rate of nitrogen fertilizer can also be added in the model through this section. All the model parameter regarding to the farming information are given in the Table 3.2.

Table 3.2: Model parameter for farming information

Name of Input Parameter	
Transplanted/Harvested	Transplanting Date
	Harvest Date
	Application of Nitrogen Fertilizer (kgN/ha)
	5-day mean air temperature before transplanting (°C)
	Flooding date (MM/DD)
	Drainage date (MM/DD)
	Water depth(m)

3.3.1.3 Parameter for OM incorporation information

It is the final interface in which the applied OM types and content are given as inputs to the model. Dates of OM application in the rice fields are the basic data that are added at first. In OM type, model is capable to simulate and calculate the emission of methane from different OM types such as wheat straw, wheat root, rice straw, rice root, green manure, farm manure etc. The model is also capable of performing with multiple types of OM at the same time. All the model parameter regarding OM incorporation information is given in the Table 3.3.

Table 3.3: Model parameter for organic matter incorporation information

Name of Input Parameter	
OM Type Content	Organic matter application date (MM/DD)
	Grain yield of the previous crop (kg/ha)
	OM ratio of previous yield
	OM Amount (kg/ha dry)
	Organic matter type

3.4 Calculation of Influence of Agro-climatic Factors on the Rate of Methane Emission from Irrigated Boro Rice Fields

Methane emission from any rice field is influenced by several factors. Some of them are due to climatic variables and others are due to the agricultural variables. Both variables are collectively defined in the study as agro-climatic factors. From the extensive literature review several agro-climatic factors has identified. Among them the effects was calculated for only those factors which can be simulated through the model. So, only the effects of maximum temperature, elevated concentration of atmospheric CO_2, soil properties, chemical fertilizer, types of OM, rice cultivars and different water management practices (number of intermittent irrigation and drainage) were calculated for this study. When the effect of one factor was calculated the other factors were assumed to remain the same or unchanged. All the analyses were carried out for BRRI dhan 28 and BRRI dhan 29 to represent the effects from Boro rice cultivation at the study area.

3.5 Projection of Future Emission Scenario

The country's future methane emission scenarios from the existing pattern of Boro rice (from both BRRI dhan 28 and BRRI dhan 29) cultivation and management practice were calculated through the model. Daily atmospheric temperature (both maximum and minimum), precipitation and concentration of CO_2 were the only variables which were updated with the projection year 2030 and 2050. A study (CCC, 2009) was carried out to predict the future (in the year 2030, 2031, 2050, 2051, 2070, and 2071) maximum and minimum temperature and precipitation with the help of regional climate modeling systems called PRECIS (Providing Regional Climates for Impacts Studies) for different grids of Bangladesh by using SRES (Special Report on Emissions Scenarios) A1B emission scenario as an model input with the base year from 1961 to 1990. A world of rapid economic growth, a global population that reaches 9 billion in 2050 and then declines, the quick spread of new and efficient technologies, a convergent world (i.e. extensive social and cultural interactions worldwide) with a balanced emphasis on all energy sources are the basic characteristics of A1B emission scenarios. From the study, projected maximum and minimum temperature and precipitation data of Tangail district (grid number is 1991) for the year 2030 and 2050 were collected and are given in the Table 3.4.

Table 3.4: Projected maximum and minimum temperature and precipitation data for the year 2030 and 2050

Months	**Maximum Temperature (°C)**		**Minimum Temperature (°C)**		**Precipitation (mm/day)**	
	2030	**2050**	**2030**	**2050**	**2030**	**2050**
JAN	22.93	24.95	8.83	10.46	0.28	0.42
FEB	28.13	29.65	13.81	15.49	0.32	0.89
MAR	36.44	38.45	21.45	23.46	1.44	1.19
APR	38.82	40.62	27.14	28.67	1.13	2.22
MAY	36.76	37.69	28.39	29.37	2.86	3.32
JUN	35.09	37.50	28.00	29.45	6.26	5.37
JUL	33.94	35.48	27.13	28.20	7.69	8.46
AUG	34.14	35.45	26.94	27.97	6.55	7.84
SEP	33.12	34.35	26.35	27.44	5.40	4.67
OCT	31.25	33.06	23.21	24.51	2.44	2.25
NOV	26.12	29.16	15.98	18.08	0.74	0.47
DEC	22.22	24.76	10.16	12.41	0.42	0.78
Concentration of atmospheric CO_2 (Nigel and Osborne, 2011)			**In the Year 2030**		**In the year 2050**	
			452 ppm		532 ppm	

3.6 Identification of Possible Mitigation Measures

The possible mitigation measures to turn down the rate of methane emission form irrigated Boro fields at the study area were identified through literature review. The percentage of reduction methane emission from the possible mitigation measures (application of AWD, changing of rice cultivars, reduction of nitrogen fertilizer and OM application rate, direct seeding and shifting of transplanting date) was computed through the model. The feasibility and potentiality of application of these mitigation measures at the study area were tested by considering the farmer's perceptions during the FGD.

3.7 Selection of the Study Area

The study was carried out to identify the country status of methane emission from irrigated Boro rice cultivation as well as to assess the potentiality of different mitigation measures. Intensity of rice cultivation and geo-climatic pattern over the whole country are not similar. The Northwest part of Bangladesh is drought prone, the southwest part has the salinity problem, the northeast part has the wetlands with flash floods and the southeast part is the hilly region. To overcome those complexities, Tangail district was selected to estimate the methane emission from the whole country. This is because Tangail district is situated more or less in the central hydrological zone of the country and it has all the climatological data with a long history of irrigated Boro rice cultivation.

The effects of different agro-climatic factors on methane emission were identified by using the model and were calculated for Gazipur district. It is also an intensified rice cultivation zone in Bangladesh. According to BADC (2009), it was found that, more than 58% of the total cultivable land of Gazipur district is irrigated by three broad methods of irrigation i.e. Deep Tube Wells (DTWs), Shallow Tube Wells (STWs) and Low Lift Pumps (LLPs). Moreover, the district has a wide history on agricultural practice and research work. The communication network is quite easier. On the basis of this information, Gazipur district was selected to conduct the study. Possible mitigation options for emission reduction were identified by discussing with the local farmers of Gazipur district. For that, three individual FGDs were conducted with the local farmers in three individual villages (Vaurait of Kayaltia union, Megdubi of Pubail union and

Niler para of Gazipur sadar) of Gazipur sadar upazilla of Gazipur district. Farmers' selection was based on the experience and duration of engaging (at least five years) with Boro rice cultivation.

For the calculation of country present status of methane emission, Gazipur district was not considered. Because, 56% of the total land of Gazipur district is comprises of upland and those are highly urbanized.

3.8 Methods of Data Collection

3.8.1 Primary data collection

The primary data for the study were collected through FGD and KII. These data were collected during the Boro season of 2011.

3.8.1.1 FGD with local farmers

To collect the primary data from the field level, three FGDs with local framers were conducted in three different unions of Gazipur district. The number of farmers in each FGD varied from 15 to 20. The farmers who were engaged with Boro rice cultivation over at least five years were the pre-mentioned criteria to participate in FGD. Both the quantitative data e.g. grain yields, aboveground biomass, application rate of nitrogen fertilizer and OM, yields of previous crop and date of transplanting, harvest etc. and qualitative data e.g. perception regarding the various emission mitigation options were collected though FGDs.

3.8.1.2 Key informant interviews (KII)

Several interviews were conducted with expert personnel of Bangladesh Rice Research Institute (BRRI) for knowing the relation of Harvest Index (HI) with straw yields, research about new rice cultivar focused on methane emission reduction, adoption rate of different Boro and Aman rice cultivars and applicability of mitigation measures in the farmer's fields. Interviews were also conducted with the concerned personnel of Department of Agricultural Extension (DAE) in Gazipur to know the local pricing system of irrigation, awareness and capacity building training and knowledge sharing programs (both present and upcoming) and also the feasibility of applying the mitigation measures in the study area.

3.8.2 Secondary data collection

Besides the primary data, the study required some secondary data to run the model as well as to complete the study. Daily maximum and minimum temperature and precipitation data for the county were collected from Bangladesh Meteorological Department (BMD). Same data for the Gazipur district were collected form the weather station of BRRI. For the projection of future emission rate, data were collected form CCC (2009). Current and future projected rate of atmospheric CO_2 concentration were collected from NOAA-ESRL: Mauna Loa Observatory (2011). Soil texture data for the study area were collected form BARC (2005). Other required data for the study were collected from relevant research papers, books, journal articles and websites.

3.9 Limitations of the Study

The following are some of the limitations of the methodology followed in this study:

- For estimating the total methane emission from Bangladesh, only Tangail district was considered as the representative area, which belongs to AEZ 8. The estimation would be more accurate if other district from different AEZ is considered. But, due to time constraint, it was not feasible in this study.
- For Boro season, only BRRI dhan 28 and BRRI dhan 29 rice varieties were taken into consideration in the study. These two rice cultivars were the leading varieties all over the country although other varieties exist. Again, due to non-availability of varietal data and time constraint, it was not possible to consider other rice varieties.
- As the data were available for only A1B emission scenario, it was considered for future emission projections. It is possible to handle other scenarios through the model if the required data for other scenarios are available in future.
- In the future projection, the adoption trend of BRRI dhan 28 and BRRI dhan 29 rice varieties were considered as same was observed in 2009. As varietal development is an on-going process, new varieties would be developed in future with characteristics different from the present varieties. Similarly, annual total

harvested area was considered as constant for the years 2030 and 2050. But, with decreasing arable land due to rapid expansion of urban area, the harvested area (and hence the emission) would be lower than that estimated in this study.

Chapter 4

STUDY AREA

4.1 Introduction

It has already been mentioned that, Tangail was selected as a representative area of the country for calculating the country-wise methane emission. On the other hand, for assessing the farmers’ perception about emission mitigation measures and the possibility of adoption of the measures, FGDs were conducted at Gazipur district.

4.2 Location

The study area is lies between 23°56′N to 24°04′N latitudes and 90°24′E to 90°28′E longitudes. The location map of the study area is shown in the Figure 4.1. Besides Balu and Turag rivers, which flow through the district, it is surrounded by the Shitalakshya river in the east, and Bangshi river to the west and the old Brahmaputra to the north.

4.3 Climatic Condition

In the study area, annual average maximum temperature is 37 °C, minimum is 12.7 °C and the annual rainfall is around 2376 mm. The maximum temperature is observed during April to May and minimum temperature is observed during November to March. Major portion of rainfall in the study area occurs from June to September. The monthly average maximum and minimum temperature and rainfall are shown in the Table 4.1.

4.4 Major Land Use Pattern

The net cultivable land of the study area is around 101475 ha in which 34.84% single cropped, 50.76% double cropped, 14.40% triple cropped and 16935 ha remain fallow (BADC, 2009). Total land under irrigation is around 59% and cropping intensity is 166% (BBS, 2009). The major cropping pattern in the study area is Boro followed by Aman. Beside this, Boro followed by fallow cropping pattern was observed for the low land area of the study area.

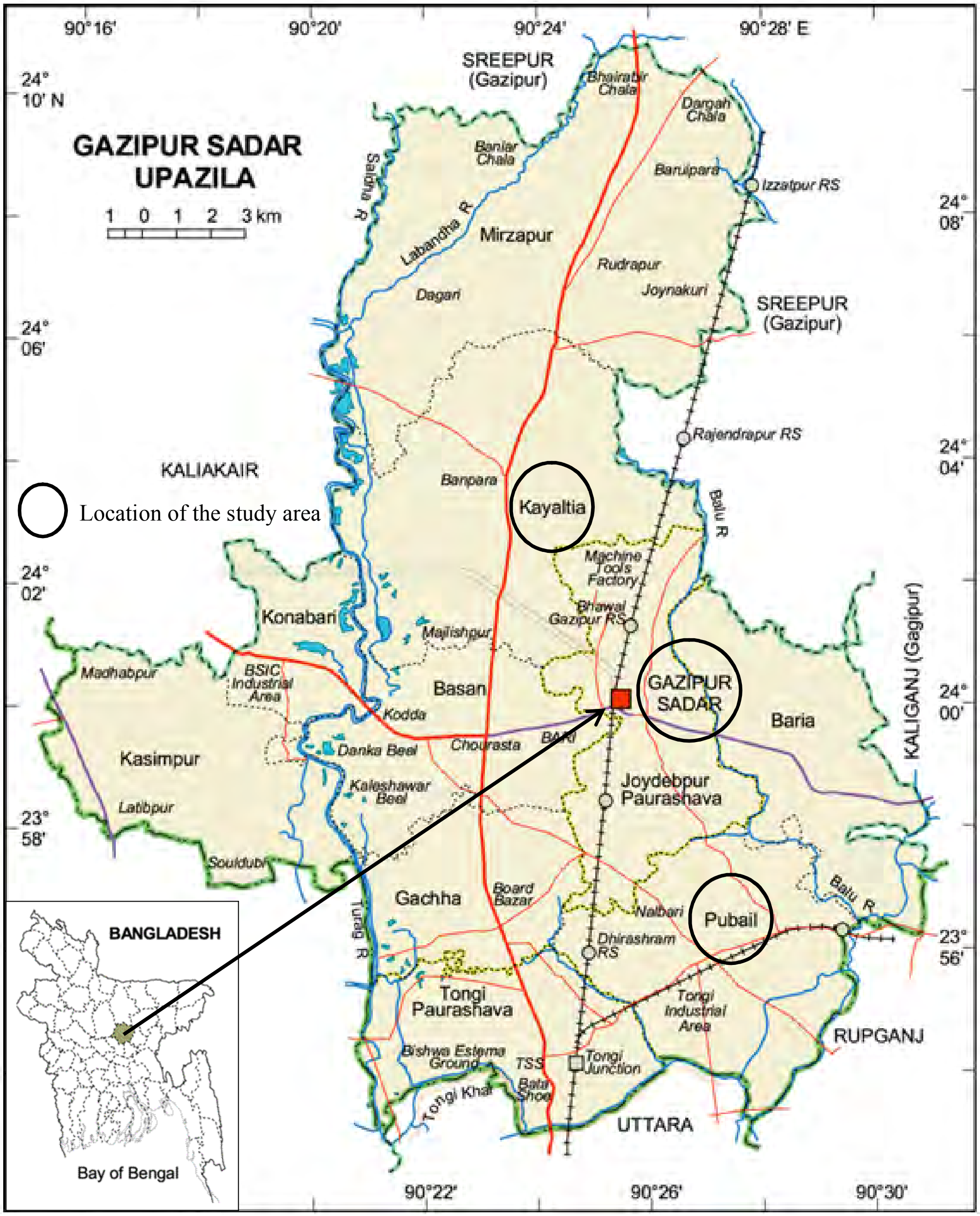

Figure 4.1: Location of the study area (*Source: Banglapedia, 2006*)

Table 4.1: Monthly average maximum and minimum temperature and rainfall of the study area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T. Max (°C)	25.9	29.7	33.3	35.1	34.6	34.5	32.4	32.5	32.8	32.2	32.2	32.2
T. Min (°C)	14.8	17.3	21.5	25.9	25.2	26.7	26.7	26.3	26.3	24.2	20.2	15.3
Rainfall (mm/day)	0	0.04	1.58	1.13	5.38	6.73	20.87	9.00	2.47	0.13	0	0
Source: BBS, 2009.												

4.5 Agro-ecological Characteristics

The study area belongs to the Agro-ecological zone (AEZ) 28 and named as Madhupur Tract. The landscape is comprises of upland (around 56% of the total land). Average soil pH is 4.8 to 5.5 i.e. strongly in acidic nature. Moisture holding capacity and status of the OM is low (BARC, 2005). Soil type of the study area lies in the category of Red-Brown Terrace soils which is characterized as well to moderately well-drained, red and brown, strongly acid, clay loams and clays, part over compact Modhupur clay at 1-3 feet, part over deeply mottled clay substratum (BBS, 2004).

4.6 Irrigation Status

Surface water of the study area, especially the river water is extensively polluted due to the excessive industrial activities. Thus ground water from DTWs and STWs is the major source of irrigation in the study area. Source of energy for the operation of both DTWs and STWs are electricity and diesel. In the study area, the pricing for irrigation water supply is mostly area based. The irrigation status of the study area for the most recent year (2009) is given in the Table 4.2.

Table 4.2: Irrigation pattern of the study area

Total area (ha)	Total cultivable area (ha)	Irrigated area by DTWs (ha)	Irrigated area by STWs (ha)	Irrigated area by LLPs (ha)	Irrigated area by traditional method (ha)	Irrigated area by gravity flow (ha)	Total irrigated area by all methods (ha)
180000	101475	16528	30188	12458	108	990	60272
Source: BADC, 2009.							

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Introduction

Rice cultivation, specifically the irrigated Boro rice, is the key source of methane production and emission from contemporary agricultural practice. This is because the cultivation is evolved with anaerobic decomposition of organic matters i.e. retained biomass of previous crop, organic fertilizers etc. With the present climate change context, emission reduction is a bigger challenge, especially, for the most rice producing counties in the world. In the study, country's present scenarios with respect to methane emission as well as the projection of future emission from the same context were studied. The most significant factors that affect the emission rate and their effects were calculated. Finally, the appropriate and possible mitigation measures to reduce and control the rate of methane emission from Boro rice fields were studied.

5.2 Methane Emission from Irrigated Rice Field by Using the IPCC Guidelines

In a particular given area, methane emission is the function of several factors, such as cropping pattern, duration of crops growth, water regimes (before and during the cultivation period), application period, rate and types of organic amendments, rice cultivar, soil texture and pH, climatic parameter like temperature, concentration of atmospheric CO_2 etc., (IPCC, 2006). By considering these factors, in 2006, IPCC modified and revised the emission equation which was developed in 1996 and revealed in the Guidelines for National Greenhouse Gas Inventories, (equation 3.1).

5.2.1 Calculation of annual harvested area for Boro and Aman season

In this study, only two rice cultivars i.e. BRRI dhan 28 and BRRI dhan 29 for Boro rice and only one rice cultivar i.e. BR 11 for Aman rice were considered. On national scale, BRRI dhan 28 and BRRI dhan 29 are the most prominent and their adoption rates were almost 40% and 60%, respectively to the total harvested area in a given year (BRRI, 2006) and the same proportion was also observed during the FGD. On the other hand, BR 11 was the most common variety of Aman rice (BBS, 2009).

In local practice, rice straw incorporation of previous crop was the major source of organic amendments which enhance the rate of methane emission. Although local varieties of rice are grown during both Boro and Aman seasons. But their adoption rates are nominal. Moreover, the plant height of local varieties is lower, so, straw incorporation rate for local varieties is not quite high. So, the contribution of local varieties to annual methane emission was considered as negligible.

Total cultivation period (t_i) for all varieties were considered as 120 days with three distinct phases i.e. vegetative (duration is 60 days), reproductive (duration is 30 days) and ripening (duration is 30 days) (BRRI, 2002). The double cropping pattern (Boro followed by T Aman) was considered for the whole country and the total annual harvested area (A_i) for BRRI dhan 28, BRRI dhan 29 and BR 11 was calculated according to their adoption rate and shown as Table 5.1. The table revealed that, adoption rate for all the selected varieties have gradually increased. The annual harvested area of MVs (Modified Varieties) during the Aman season was considered as the annual total harvested area of BR 11 variety.

5.2.2 Consideration of baseline emission factor (EF_c)

IPCC have provided the default value of baseline emission factor for different rice cultivation practices. From those given default values, the default value of baseline emission factor for both types of rice cultivation was considered as 1.30 kg CH_4 ha^{-1} d^{-1} (IPCC, 2006). The selected condition represents no flooded fields for less than 180 days prior to rice cultivation and continuously flooded during the rice cultivation period without organic amendments.

5.2.3 Scaling factor for water regimes during the cultivation period (SF_w)

In the study, irrigated and continuously flooded water regime for Boro rice and regular rainfed water regime for Aman rice were considered. In case of Boro rice, the scaling factor was considered as 1. On the other hand, for Aman rice the scaling factor was considered as 0.28 (IPCC, 2006).

Table: 5.1 Calculation of annual harvested area for Boro and Aman seasons

Year	Annual harvested area for Boro (ha)			Annual harvested area for Aman (BR 11) (ha)	Country total harvested area (ha)
	Country total	BRRI dhan 28 (40% of total)	BRRI dhan 29 (60% of total)		
2000	3424790	1369916	2054874	2760560	6185350
2001	3560100	1424040	2136060	2796530	6356630
2002	3569180	1427672	2141508	2864660	6433840
2003	3666900	1466760	2200140	2938280	6605180
2004	3735220	1494088	2241132	2985890	6721110
2005	3875840	1550336	2325504	2906010	6781850
2006	3891600	1556640	2334960	3193480	7085080
2007	4268000	1707200	2560800	3814000	8082000
2008	3538000	1415200	2122800	3739000	7277000
2009	3850000	1540000	2310000	4039000	7889000
Source: BRRI, 2003.					

5.2.4 Scaling factor for water regimes in the pre-season before the cultivation period (SF_p)

As the emission estimation was for the double cropping pattern throughout the whole cultivation period, so, fields were not flooded during pre-season (180 days prior to transplantation). Under this selected water regime, the scaling factor was considered as 1 (IPCC, 2006).

5.2.5 Scaling factor for organic amendments (SF_o)

Methane emission from rice field is influenced by the rate and type of organic matter applied. More methane is emitted from the organic amendments which contain higher amounts of easily decomposable carbon.

During the FGD, that was conducted in three different unions of Gazipur district, all of the farmers told that, as organic fertilizer, they used the rice straw which remained in their rice fields after harvesting. A few of them (around 30%) replied that, they use farm manure (cow dung) in addition with rice straw as organic fertilizer. So, for this calculation, only the rice straw and farm manure were used as the source of organic amendments. The scaling factor for organic amendments was calculated by using the Equation 3.3.

5.2.5.1 Consideration of conversion factor for organic amendments (CFOA)

As only two sources of organic matter were incorporated into the rice fields in both seasons, the conversion factors in the study were considered for both types of organic amendments. For the selection of conversion factor for organic amendments (rice straw), the straw incorporated shortly (less than 30 days) before cultivation was considered. The farmers during FGD informed that, 15 to 20 days before transplanting they plough the land as the part of land preparation. When plough is applied, they break down the soil texture and thus the straw of previous crop which was retained after the harvesting is mixed up with the soil and treated as the source of organic amendments for the methane emission. The same practice was applied during both seasons of rice cultivation.

So, for the incorporated straw (less than 30 days before cultivation) and farm manure, the conversion factors were considered as 1 and 0.14, respectively (IPCC, 2006).

5.2.5.2 Computation of rate of rice straw incorporation ($ROA_{i\ RS}$)

In this study, yield was considered as 3.62 t/ha, 4.5 t/ha and 5.5 t/ha for BR 11, BRRI dhan 28 and BRRI dhan 29, respectively because during the FGD farmers informed those yield rates from their fields. The yields compared well with the average yields of these varieties (BRRI, 2006).

Dry weight of straw was calculated by using the HI which is the ratio of grain weight vs. total weight (including grain and straw). So, the variety which has high HI has low straw yield. The HI for the selected rice varieties is shown in Table 5.2. From the table it has observed that, BRRI dhan 29 contain the maximum HI i.e. 0.49 compared to the other two rice varieties.

Table 5.2: Harvest Index (HI) of the selected rice varieties

Name of rice varieties	HI
BR 11	0.42
BRRI dhan 28	0.42
BRRI dhan 29	0.49
Source: BRRI, 2002	

The heights of selected varieties were 115 cm, 90 cm and 95 cm, respectively (BRRI, 2010). Most of the farmers told that, during harvesting, they cut off the rice plant from at least 7 inches i.e., about 18 cm above the ground. Thus 18 cm of rice straw is incorporated as organic amendments during the land preparation. The straw yield and straw retained in the fields after harvesting are shown in the Table 5.3.

According to the table, BRRI dhan 28 has the highest straw yields compared to other two varieties. As the plant height of all three varieties is not same, so, the proportion of straw retained in the rice fields was not same. For instance, about 1.24 t/ha and 1.14 t/ha straw were retained in the rice fields after harvesting for BRRI dhan 28 and BRRI dhan 29, respectively which is almost 20% of straw yields for each of the varieties. But for BR 11, the proportion was around 16% (Table 5.3).

Table 5.3: Rate of straw yield and straw retained in the fields for selected varieties

Name of the variety	Straw yields t/ha	Straw retained in the field after harvesting t/ha
BR 11	5	0.773
BRRI dhan 28	6.21	1.24
BRRI dhan 29	5.72	1.14

In T. Aman followed by Boro cropping pattern, the rice straw which was retained in the field after the harvesting of Aman, is applied as an input organic matter for Boro rice. The application rate of rice straw for different varieties is shown as Table 5.4.

In the Table 5.4, two types of application rates (calculated and actual) have been defined. For Aman rice, the calculated application rate was not considered. When T. Aman is followed by Boro cropping pattern, the calculated amount of rice straw does not take part in active decomposition process for methane emissions. The farmers informed that, after harvesting of Boro rice, although, they have retained the calculated amount of rice straw, but, when they use their Boro fields for Aman cultivation, around 70% of rice straw that they have retained in the fields after Boro harvesting disappear during the time interval between Boro and next Aman. So, the actual application rate of rice straw was calculated further and given in the Table 5.4. In case of Boro cultivation, due to the shorter time interval of Aman to the immediate Boro, all of the rice straw that the farmers have retained in their fields after harvesting of Aman, actively participate in the methane formation process.

Table 5.4: Application rate of rice straw for selected varieties

Name of the variety	**Calculated application rate of rice straw t/ha**	**Actual application rate of rice straw ($ROA_{i\ RS}$) t/ha**
BR 11	1.19	0.350
BRRI dhan 28	0.773	0.773
BRRI dhan 29		

5.2.5.3 Computation of rate of farm manure incorporation

In addition to rice straw, animal manure was another organic amendment which was applied in the rice field during the land preparation. Local farmers told that due to the shortage of food and scarcity of land for rearing, number of cattle has become reduced in the recent years. As a result, they are incapable of incorporating the rate of farm manure as they did earlier. The rate of farm manure use was 3.7 to 15 t/ha. According to the KII, it was considered as 6 t/ha. This weight was fresh weight. But during FGD, only 30% of the farmers replied that they are able to incorporate farm manure at such amount. So, on an average, the application rate of farm manure was considered as 1.9 t/ha (fresh weight) i.e., $ROA_{i\ FM}$ is 1.9 t/ha. This practice was almost same for all types of rice cultivation. From FGD and KII it was observed that, the ratio of water and dry matter in the fresh weight of farm manure is 7:3. So, for dry weight consideration, the application rate of farm manure was around 0.6 t/ha.

5.2.5.4 Calculation of scaling factor for organic amendments

As rice straw and farm manure were applied in the rice cultivation so, to calculate the scaling factor for rice straw and farm manure simultaneously, the Equation 3.3 has been modified as Equation 5.1. Modified equation, for scaling factor calculation, is shown below.

$$SF_o = [1 + \{(ROA_{i\,RS} \times CFOA_{i\,RS}) + (ROA_{i\,FM} \times CFOA_{i\,FM})\}]^{0.59} \qquad (5.1)$$

By putting the value of $ROA_{i\,RS}$ (from the table 5.4), $ROA_{i\,FM}$ (from the section 5.2.5.3), and $CFOA_{i\,RS}$ and $CFOA_{i\,FM}$ (from the section 5.2.5.1) in the previous equation, scaling factor for BR 11 was calculated as 1.33 and for BRRI dhan 28 and for BRRI dhan 29 it was calculated as 1.52.

5.2.6 Computation of methane emission from different rice field

After considering all of the scaling factors, the methane emission form different rice cultivars were calculated and the results are shown in Table 5.5.

From the table it can observed that, the annual rate of methane emission for Aman rice (BR 11) is lowest i.e., 5.8×10^{-5} Gg CH_4 ha^{-1} yr^{-1} compared to the other two varieties of Boro rice. This is because, Aman rice is totally rainfed, and no irrigation is required during its cultivation period. Hence, several wetting and drying cycles occur during Aman season. As standing water in the rice field throughout the whole growing period is required for methane emission, the wetting and drying cycles ultimately reduce the rate of emission. For BRRI dhan 28 and BRRI dhan 29, which are totally irrigated, annual emission was 23.7×10^{-5} Gg ha^{-1} (Table 5.5).

Table 5.6 represents the total methane emission from 2000 to 2009 in the country. It shows a gradual increasing trend, except in 2008. Rate of emission in the year 2008 was lower compared to 2007 because the total cultivable area in 2007 was 8.08 million ha where as for 2008 this figure was 7.28 million ha.

Table 5.5: Annual rate of methane emission for selected rice varieties

Name of the variety	Annual methane emission, Gg CH_4 ha^{-1} yr^{-1}
BR 11	5.8×10^{-5}
BRRI dhan 28	23.7×10^{-5}
BRRI dhan 29	

On an average, around 1071 Gg of methane has been emitted annually form both the Aman and Boro rice cultivation. A comparison of table, 5.1 and 5.6 would show that the emissions are related to the cultivated area.

The daily rate of methane emission for Boro (197.5 mg m^{-2} d^{-1}) season was three times higher than that of Aman (48.3 mg m^{-2} d^{-1}) season (Table 5.6). Among the selected three different rice cultivars, emission rate was higher in BRRI dhan 29 for all the years (Table 5.6). But for both types of Boro rice verities, emission rate was calculated as same. Theoretically it was not correct. Because, the mechanism of methane emission shows that, when the rate of yield is high in any variety, then the rate of methane emission will be higher for that variety, due to more duration. As a limitation of methodology prescribed by IPCC, all the factors and variables were same for every year. Here harvested area was the only single variable. As the adoption rate of BRRI dhan 29 was higher compared to all other selected varieties, so emission rate was estimated higher in BRRI dhan 29.

5.3 Methane Emission from Irrigated Rice Field by Using the CH4MOD2.5 Model

The rate of annual methane emission for the country was also computed by using the CH4MOD2.5 model. A detail description of the model and required data to run it are given in the section 3.3 and 3.3.1 respectively. Considering the intensity of rice cultivation and availability of data for rice cultivation, Tangail district was selected as the representative of whole country. According to the BARC (2005), Tangail is situated in the AEZ 8. All the characteristics of AEZ 8 (Altitude, soil pH, soil texture) were considered as the representative value of Bangladesh. The climatic parameters like maximum temperature, minimum temperature and precipitation on per day basis, are required to run the model. These data were long term average. Atmospheric concentration of CO_2 is an important variable for this estimation and the CO_2 data were taken from NOAA-ESRL: Mauna Loa Observatory (2011). Aboveground biomass on transplanting date and OM amount were considered from Table 5.4 and section 5.2.5.3, respectively. Transplanting, harvesting and flooding dates were considered from local farmers' information during FGD. All the input parameters for model are shown in Table 5.7.

Table 5.6: Country total annual methane emission from both the Aman and Boro rice cultivation

Year	**Annual total emission for BR 11, Gg**	**Annual total emission for BRRI dhan 28, Gg CH_4**	**Annual total emission for BRRI dhan 29, Gg CH_4**	**Seasonal emission, Gg CH_4**		**Country total annual emission, Gg CH_4**
				Aman	**Boro**	
2000	160.11	324.67	487.00	160.11	811.67	971.78
2001	162.20	337.50	506.25	162.20	843.75	1005.95
2002	166.15	338.36	507.54	166.15	845.90	1012.05
2003	170.42	347.62	521.43	170.42	869.05	1039.47
2004	173.18	354.10	531.15	173.18	885.25	1058.43
2005	168.55	367.43	551.14	168.55	918.57	1087.12
2006	185.22	368.92	553.39	185.22	922.31	1107.53
2007	221.21	404.61	606.91	221.21	1011.52	1232.73
2008	216.86	335.40	503.10	216.86	838.50	1055.36
2009	234.26	364.98	547.47	234.26	912.45	1146.71
Decade (from 2000 to 2009) average rate of emissions						***1071***
For Aman rate of emission was around 48.3 mg m^{-2} d^{-1}			For Boro rate of emission was around 197.5 mg m^{-2} d^{-1}			

Figure 5.1 shows the model result of daily rate of emission for selected three different rice cultivars. From the figure it has observed that, on an average, the rate of per day methane emission for BRRI dhan 29 was highest (96.73 mg m^{-2} d^{-1}) among the three varieties. It was only because of the more duration and higher rate of yield. Where as,

emission rate for BRRI dhan 28 was 27.72% lower than (69.92 mg m^{-2} d^{-1}) that of BRRI dhan 29.

The model is applicable for Boro rice cultivation, but, to provide the actual scenario of annual rate of methane emission from Bangladesh, emission rate from Aman rice is also required. The mean rate of two Boro rice varieties was 83.33 mg m^{-2} d^{-1}. According to the Table 5.5, the emission ratio of Aman rice to Boro rice was 24.47%. On that basis, it was calculated that, the emission rate for BR 11 rice (20.4 mg m^{-2} d^{-1}) was 70.82% and 78.91% lower than the rate of BRRI dhan 28 and BRRI dhan 29 respectively (Figure 5.1).

Table 5.7: Input data for running the model

Name of Input Parameter				**Data**	**Data Source**
General	*Site general parameters*	Longitude		89.92°E	Wikipedia, 2011
		Latitude		24.30°N	
		Altitude (m)		10	
		Atmospheric concentration of CO_2 ppm	2000	370.47	NOAA-ESRL: Mauna Loa Observatory, 2011
			2001	372.38	
			2002	374.92	
			2003	377.03	
			2004	378.43	
			2005	381.36	
			2006	382.88	
			2007	385.42	
			2008	386.92	
			2009	388.45	
	Rice growth	Aboveground biomass on transplanting date (kg/ha)	For BRRI 28	773	FGD
			For BRRI 29		
		r (instinct growth rate)		0.08	Model default value
		Cultivar Index (VI)		1	

		Grain Yield (kg/ha)	For BRRI 28	4500	FGD
			For BRRI 29	5500	
	Soil texture	Soil pH		6.5	BARC, 2005
		Sand (0-1)		0.3	
		Clay and Silt		0.7	
Farming management	*Transplanted/Harvested*	Transplanting Date		01.15	FGD
		Harvest Date		05.15	
		Application of Nitrogen Fertilizer (kgN/ha)		120	
		5-day mean air temperature before transplanting (°C)		17.61	BMD (Undated)
		Flooding date (MM/DD)		01/15	FGD
		Drainage date (MM/DD)		05/01	
		Water depth(m)		0.05	
Organic Matter Incorporation	Organic matter application date (MM/DD)			01/08	FGD
	Grain yield of the previous crop (kg/ha)		For BRRI 28	3620	
			For BRRI 29		
	OM Type and Content	OM ratio of previous yield		0	
		OM Amount (kg/ha dry)		600	
		Organic matter type		Farm Manure	
		OMn (%)		25.348	Model default value
		OMs (%)		74.652	

Ratio of contribution to methane emission annually from three different rice cultivars is shown in the Figure 5.2. It can be observed that, emissions from both the Aman and Boro rice show a gradual increasing pattern. During the last ten year (from 2000 to 2009), on an average, country emitted 464 Gg methane from its rice field. Out of this, the contribution of Aman rice is only 17% and the rest of 83% of methane emission is contributed from Boro rice cultivation.

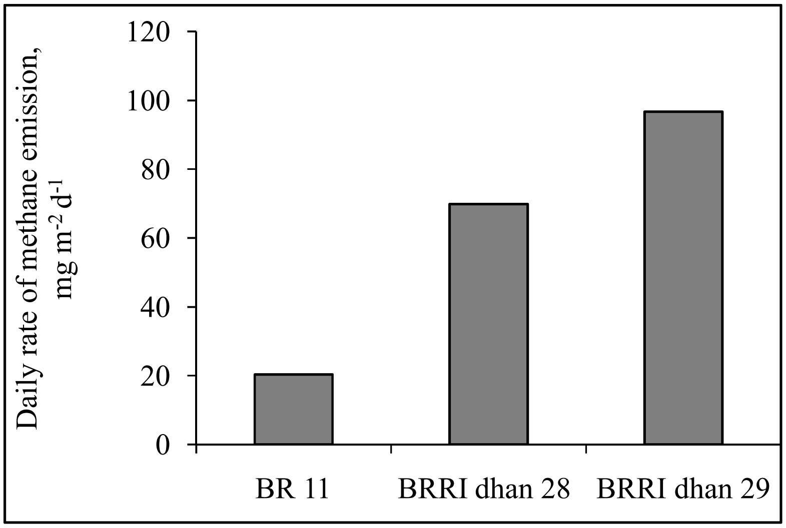

Figure 5.1: Daily rate of emission for selected three different rice cultivars (using CH4MOD2.5 model)

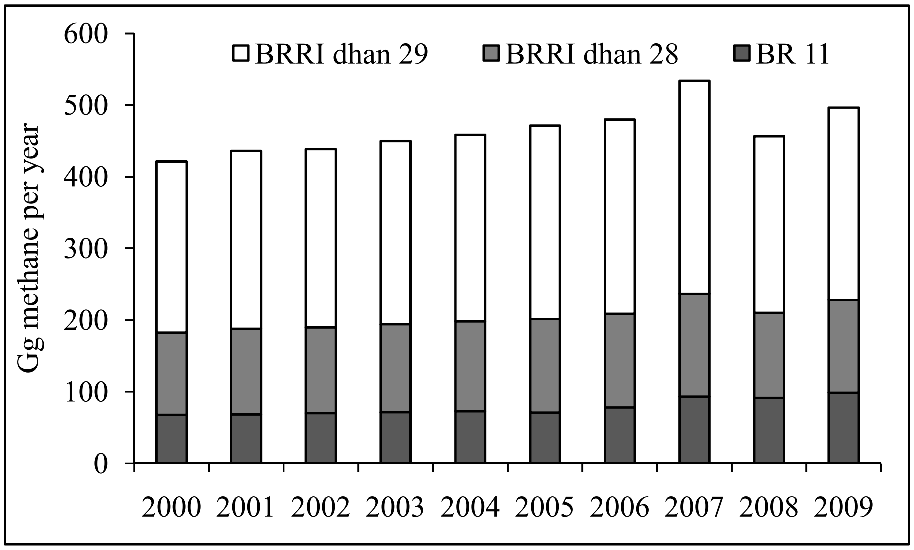

Figure 5.2: Ratio of contribution to annual methane emission from three different rice cultivars

5.4 Comparison of Different Rates of Methane Emission

US-EPA (United States Environmental Protection Agency) has provided a projection regarding the future rate of methane emission form developing countries through rice cultivation. In that report, they estimated that, Bangladesh will contribute on an average

850 Gg and 918 Gg CH_4 annually from rice cultivation (including all types of water regimes) in 2005 and 2010, respectively. By using the methodology that is suggested by IPCC (2006), this figure was 1087 Gg in 2005 and 1146 Gg in 2009. On the other hand, the CH4MOD model, used in the study, the estimated CH_4 was 471 Gg and 496 Gg for the year 2005 and 2009 respectively (Figure 5.3).

In the Figure 5.3 it can be observed that, there are huge differences between these three methods of estimations. Among the three methods, emission was highest in IPCC (2006) methodology and lowest in CH4MOD model result, for both the year 2005 and 2009.

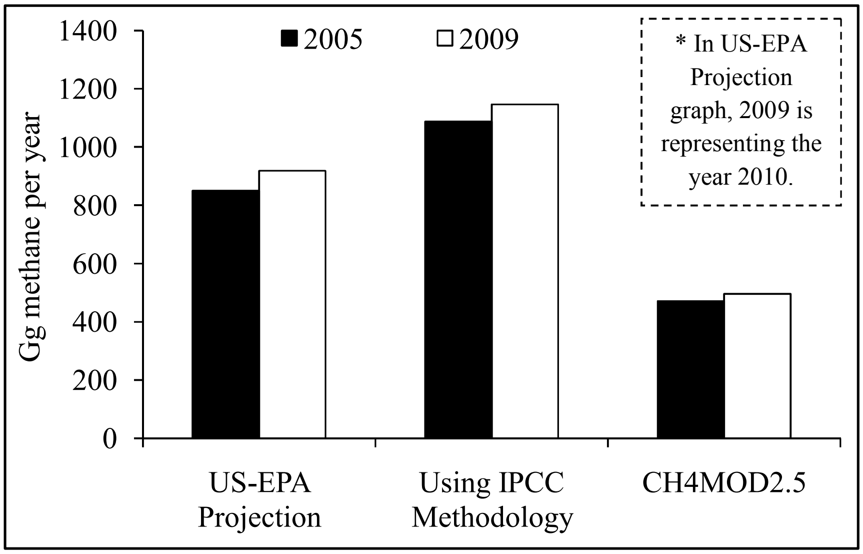

Figure 5.3: Comparison of methane emission rate from three different methods

The CH4MOD estimation was 45% (approximately) lower than the EPA projection value (Figure 5.3). This variation occurred, firstly because, US-EPA projection was also based on IPCC methods but the earlier version (IPCC, 1996) and secondly, they considered all types of water regime including upland, irrigated, rainfed, and others for that estimation. But in the CH4MOD model, only the rainfed and continuous flooded water regime for rice cultivation were considered.

5.5 Agro-climatic Factors Influencing the Rate of Methane Emission

Emission of methane from irrigated rice fields varies significantly with different agro-climatic factors, which includes daily average of maximum and minimum temperature, application rate of fertilizer and organic amendments, different rice cultivars, concentration of atmospheric CO_2, soil type, soil pH, tillage, different kinds of water management practice and so on. Among these, some factors positively affect the rate of emission and some of them negatively affect the emission rate of methane from rice cultivation. CH4MOD2.5 is capable to calculate the influence of some factors' on the rate of methane emission. In this study, contributions of some of the aforementioned factors to the emission rate of methane from Boro rice fields was calculated for Gazipur district was carried out by using the model.

5.5.1 Effects of temperature

Among the other climatic parameter, atmospheric temperature is the most significant factor which positively affects the rate of methane emission from irrigated rice fields. Methane formation and emission from continuously flooded rice fields, is the combination of several microbial decomposition that is governed by several methanogens and methanotrops bacteria. Increasing of atmospheric temperature (particularly the maximum temperature) stimulates the rate of emission by increasing the rate of decomposition of organic amendments and plant roots.

To run the model for every year, all of the model inputs were same for the both varieties except the air temperature and 5-day mean air temperature before transplanting. According to the AEZ number of Gazipur district (AEZ 28), the data for soil pH, soil profile (proportion of sand to silt and clay) and application rate of nitrogen fertilizer (kgN/ha) were considered as 5.2, 0.4 to 0.6 and 110, respectively. The average value of atmospheric concentration of CO_2 (380 ppm) was considered as the model input value for every year. All other remaining parameters were the same as shown the Table 5.7.

Figure 5.4 shows the seasonal rate of methane emission from different two Boro rice cultivars. The similar trend of methane emission for both the BRRI dhan 28 and BRRI dhan 29 have observed in the figure. From 2000 to 2002, gradual decreasing patterns have observed. On the other hand, it followed a reverse trend from 2003 to 2005. After a sharp fall in 2006, it also showed an increasing pattern in the following year. The variation on emission rate was only due to the variation of atmospheric temperature especially the maximum temperature. Although, both the maximum and minimum temperature is increasing with the every year, but, the trend was not similar for every year. For instance, in 2004, the daily average maximum temperature was 30.93 °C for the whole growing stage of rice and for the year 2005 and 2006 this rate was 32.08 °C and 30.55 °C, respectively.

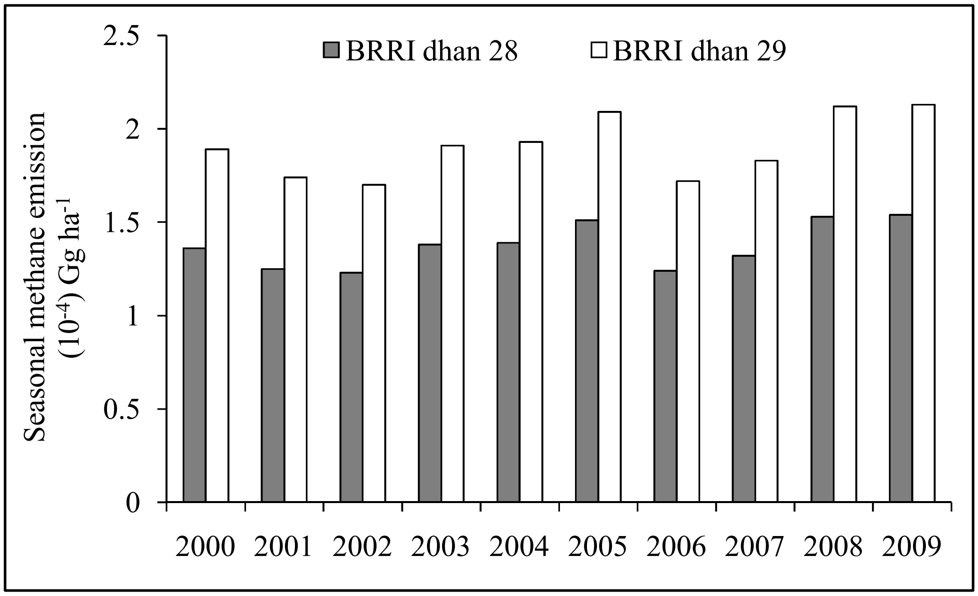

Figure 5.4: Seasonal contribution to methane emission from two Boro varities in Gazipur

5.5.2 Effects of carbon dioxide

Atmospheric concentration of CO_2 is another significant climatic factor that positively affects the rate of methane emission from rice field. Increasing the level of CO_2, leads to increasing the growth of rice plants as well as roots and thus enhances the emission rate.

The Figure 5.5 shows the effect of CO_2 on methane emission in the study area. The computation was done through using the model. Initially, all the model inputs except for the concentration of CO_2, were fixed. For both the rice varieties (BRRI dhan 28 and

BRRI dhan 29), the effect was estimated as positive both in 2000 as well as in 2009. With gradual increase of CO_2 from 18 ppm in 2000 to 2009, emission rate was enhanced at 2% for BRRI dhan 28 and 2.5% for BRRI dhan 29 (Figure 5.5). Thus, only the increasing of level of CO_2, may not lead to a rapid change on the rate of methane emission. CO_2 may significantly increase the growth rate of rice plant, but for decomposition of rice plants and roots at a faster rate, another important climatic parameter i.e. atmospheric temperature data should have to be incorporated into the model.

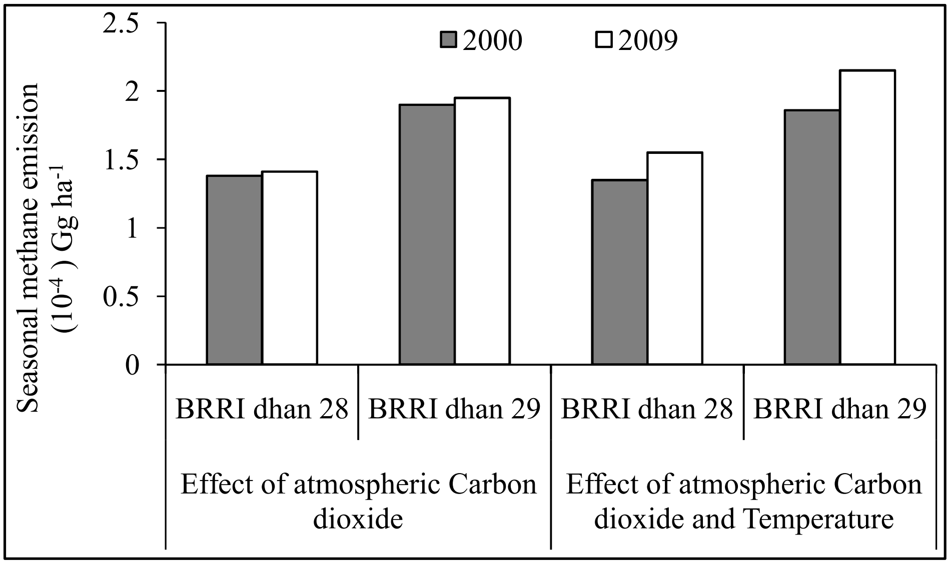

Figure 5.5: Changing effect of atmospheric concentration of Carbon dioxide on seasonal rate of methane emission form Boro rice field

Hence, the daily maximum and minimum temperature data was updated with the concentration of CO_2. That means the atmospheric concentration of CO_2 and temperature was considered simultaneously. From the figure 5.5, it can be observed that, from 2000 to 2009, the increasing trend of both the climatic factors increased the methane emission rate at 13% and 16% for BRRI dhan 28 and BRRI dhan 29, respectively. The rate was 6 to 8 times higher than that of the previous estimation (only increase of CO_2). In both cases it was observed that, the effect of CO_2 on rate of methane emission was higher for BRRI dhan 29 compared to BRRI dhan 28. The only reason behind this was the higher growth rate of BRRI dhan 29. So, atmospheric concentration of CO_2 with temperature appreciably affects the rate of methane emission form rice fields.

5.5.3 Effects of nitrogen (urea) fertilizer

Nitrogen fertilizer mediated the methane emission rate from rice field. The rate and mode of application of urea fertilizer in the rice fields can stimulate methane emission. The ultimate objective of urea application is to increase the growth rate of rice plants. So, more the growth rate more the availability of decomposed materials and more is the rate of methane emission from rice fields. Traditionally, local farmer like to use urea fertilizer at such amount, which is significantly higher than the actual recommended amount for each particular area, in the BARC (2005).

The Figure 5.6 exhibits, how the rate of nitrogen fertilizer influence the seasonal rate of methane emission from Boro rice. The computation was carried out through model and also for two selected Boro rice varieties. All the input parameters were considered as fixed, except the different application rate of nitrogen fertilizer. In all the three different application rate of nitrogen fertilizer (90 kgN/ha, 100 kgN/ha and 110 kgN/ha), increasing of 10 kg of N fertilizer per ha, enhanced the methane emission rate at 0.15% for BRRI dhan 28. But the increased rate of emission was 0.21% for BRRI dhan 29, which quite higher than the BRRI dhan 28 (Figure 5.6).

5.5.4 Effects of soil texture

Methane emission from irrigated rice fields can be radically affected by the soil texture of concerned rice fields. That means, it depends on the proportion of sand and clay in the given rice fields. As methane emission is directly subjected to the water holding capacity of particular soil, so, the texture is an important agricultural factor. The porosity of sandy soil is higher rather than the clay soil. Higher porosity means the water holding capacity of sandy soil is lower and the pore space is more or less filled by atmospheric oxygen. So, apparently, the rate of methane emission under sandy soil condition is significantly lower than that of clay soil. But, the most interesting thing is that, as the cohesive force and water holding capacity is high in clay soil, the emitted methane cannot released into the atmosphere from soil by using the pore space of cay soil. So, emission has estimated higher in the sandy soil.

The Figure 5.7 represents the ratio of methane emission from sand to clay soil for the selected two rice varieties. In BRRI dhan 29, for 30% sand containing rice fields, the rate of methane emission was 1.9×10^{-4} Gg ha^{-1} in a particular Boro season. With increasing (10%) of proportion of sand for the same variety, the rate of emission was increased at 21% (i.e. 2.4×10^{-4} Gg ha^{-1}). Similar emission pattern was observed for the BRRI dhan 28 in that particular Boro season (Figure 5.7).

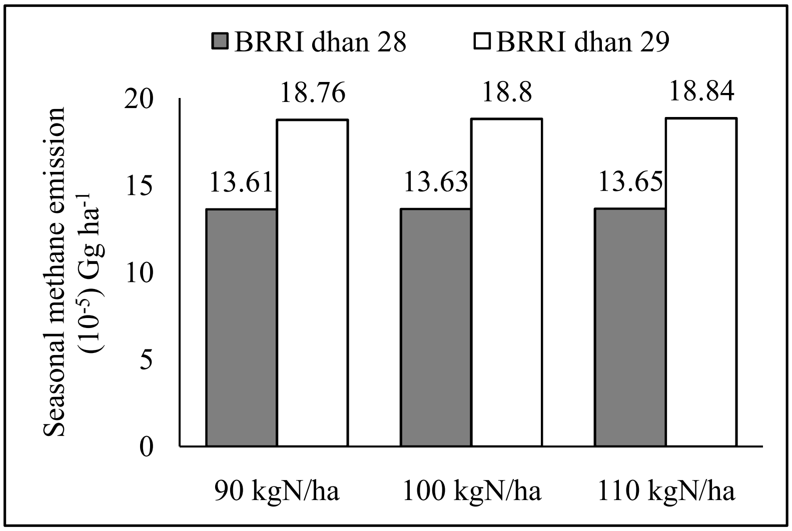

Figure 5.6: Effect of different application rate of N fertilizer on seasonal rate of methane emission

5.5.5 Effects of type and rate of organic amendments

Type of organic matter applied in the rice fields is one of the most important agricultural factors which influence the rate of methane emission. Emission rate from all kinds of organic matter is not the same. It depends on Readily Available Decomposable Materials (RADMs) into the organic amendments. Rate of methane emission is higher in that kind of organic amendments which have more RADMs.

In this study, the effect of four different organic amendments i.e. farm manure, green manure, residual decomposed OM and rice straw was calculated and shown in the Figure 5.8. The application rate for each and every organic amendment into the rice fields was considered as same. For the rice fields where farm manure was applied, gave the lowest rate of methane emission than the other three organic amendments. The highest result was estimated from using of rice straw. Incorporation of farm manure instead of rice straw reduced the methane emission at 40% in BRRI dhan 28. On the other hand, by using green manure and residual decomposed OM instead of rice straw, emission rate reduced at 20% and 15%respectively, for the same variety, (Figure 5.8). For BRRI dhan 29, those figures were found as 38%, 18% and 13%, respectively. From the model, the RADMs for the four types of organic amendments were calculated. Basically, non-structural OM is readily available for decomposition. The contents of RADMs for selected types of organic amendments were 26% (for farm manure), 38% (for green manure), 40% (for residual decomposed OM) and 49% (for rice straw). As the content of RADMs was higher in rice straw, the rate of methane emission form that particular fields was also higher.

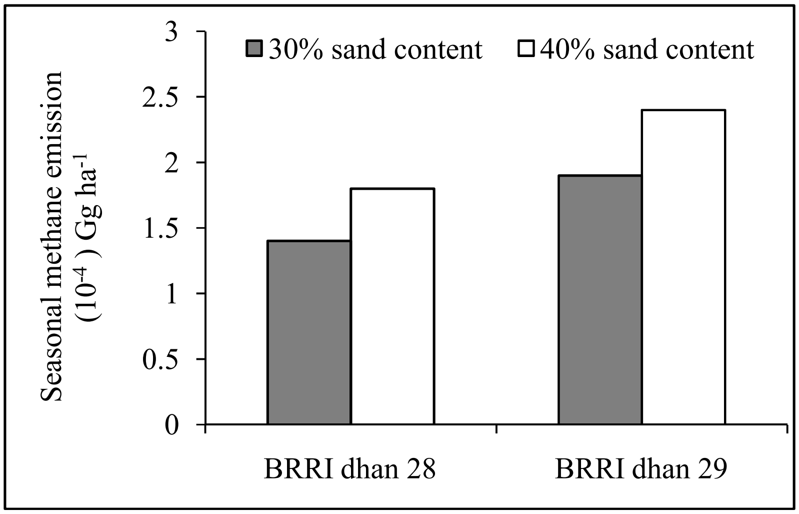

Figure 5.7: Effects of sand content into the rice fields on rate of methane emission

Like different forms of OM, rate of their application in the rice fields can effectively regulate the rate of methane emission. Farm manure is the most commonly used OM in the country’s traditional rice cultivation practices. So, how the different rates of FM application can affect the emission rates are computed through CH4MOD model. As FM act as a growth enhancing substrates for rice cultivation, so, for instance, 10% reduction of FM also required the 10% increase of nitrogen fertilizer in the normal condition or practice. In this study, FM and nitrogen fertilizer application rate for normal practice is considered as 600 kg/ha and 110 kgN/ha, respectively. The different modes of reduction of FM and subsequent increased rate of nitrogen fertilizer are shown in the Table 5.8.

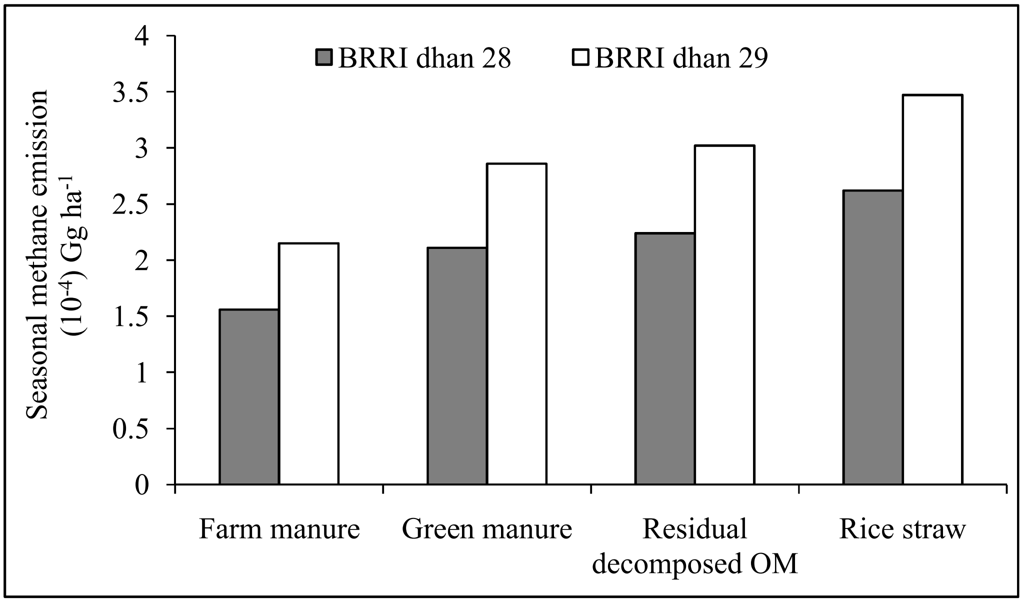

Figure 5.8: Effects of different types of organic matter into the rice fields on rate methane emission

Table 5.8: Mode of reduction of FM and increased application rate of FM and nitrogen fertilizer

Mode of reduction of FM	**Application rate of FM (kg/ha)**	**Application rate of nitrogen fertilizer (kgN/ha)**
10% reduction of FM	540	121
20% reduction of FM	480	132
30% reduction of FM	420	143

Figure 5.9 shows the effects of three different reduction mode of FM on the rate of methane emission from irrigated rice fields. According to the figure, 10% reduction of FM with 10% increased rate of nitrogen fertilizer reduced the emission of methane at around 10% for both types of rice varieties. About 19% emission reduction is estimated from 20% reduction of FM with 20% increase of nitrogen fertilizer. Similarly, in 30%

reduction of FM mode, approximately 28% methane emission is reduced from BRRI dhan 28 and for BRRI dhan 29, it was about 27%.

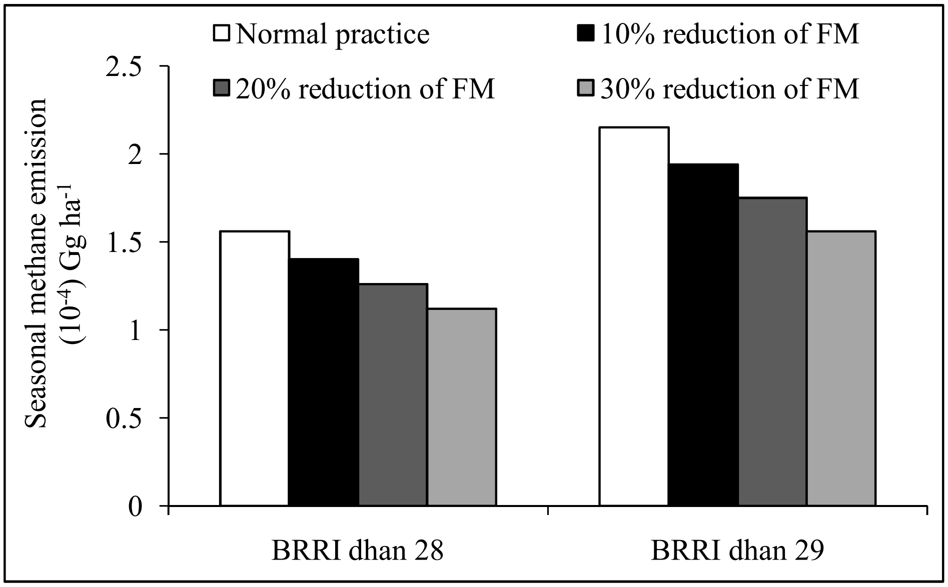

Figure 5.9: Effects of reduction of FM on the rate of methane emission form irrigated Boro rice fields

5.5.6 Effects of rice cultivars

Varieties of rice cultivars can itself act as an important agricultural factor to methane emission. Cultivars vary due to the difference in yield rate, duration of growing period, height of rice cultivar and the number of tillers. The study was carried out for two Boro rice cultivars i.e. BRRI dhan 28 and BRRI dhan 29.

The Figure 5.10 exhibits the variation of seasonal rate of methane emission for two rice cultivars. The rate of emission for BRRI dhan 29 was 27% higher than that of BRRI dhan 28. The growth period, plant height and the yield for BRRI dhan 29 were more than 120 days, 95 cm and 5.5 t/ha, respectively. On the other hand, for BRRI dhan 28, those were within 120 days, 90 cm and 4.5 t/ha. Higher yields, longer duration, more exudates and higher length govern the availability of decomposable organic matter which ultimately enhanced the emission rate.

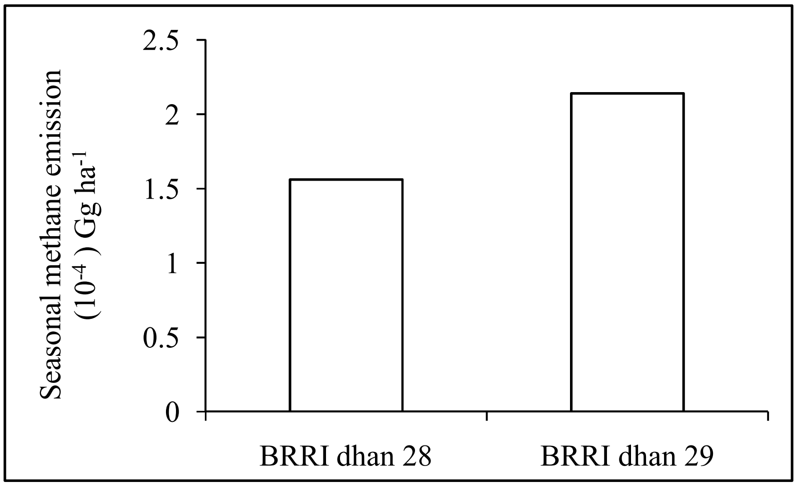

Figure 5.10: Effects of different rice cultivar on the rate of methane emission form irrigated rice fields

5.5.7 Effects of water regime

Among the all other factors, water regime itself is the most active factor which extensively influences the rate of methane emission form irrigated rice fields. This is because methane emission is mostly dependent on the type of water management practice. In continuously flooded rice fields, anaerobic environment is developed due to a certain height of stagnant water retained throughout the whole cultivation period, which radically stimulates the process of microbial degradation of organic amendments like rice straw, farm manure etc and ultimately emit methane.

A number of studies have been carried out to observe the effects of intermittent or mid season drainage on the rate of methane emission form Continuously Flooded Water Regime (CFWR). The results of those studies reveal that, Intermittent Drainage Water Regime (IDWR) dramatically reduces the emission rate. The more the number of drainage, the higher is the reduction of methane emission form CFWR (Sass et al., 1992). AWD is the most recent water management practice based on the concept of IDWR.

In this study, the effects of different number of intermittent drainages (3 IDWR, 4 IDWR, 5 IDWR and 6 IDWR) have been estimated for two Boro rice cultivars. The drainage and subsequent irrigation date was identified by the local farmers during the FGD. All the drainage date was selected only during the vegetative and ripening stage of rice plants. This is because the farmers do not like any kind of water stress during the reproductive stage of rice as it may affect the yields. All the calculations were done for a particular year (2009).

For 3 IDWR, only two drainages were provided at the early stage i.e. vegetative stage and the rest of the one drainage was incorporated in the later stage i.e. ripening. On the other hand, for 4 IDWR, the additional one drainage was added to the ripening stage compared to 3 IDWR. For 5 IDWR, the one additional drainage was added to vegetative stage conveyed to 4 IDWR. In 6 IDWR, 3 alternate irrigation and drainage (AID) was incorporated to vegetative stage and the other 3 AID were assigned to ripening stage. In all cases, no aeration was allowed to reproductive stage and the depth of irrigation for that period was 5 cm. So, approximately 7 day after irrigation, subsequent drainage was incorporated and it also extended up to next seven days.

Figure 5.11 shows the effects of different management practice on the rate of methane emission form irrigated Boro rice fields. In CFWR, methane emission was 1.56×10^{-4} Gg/ha from BRRI dhan 28 and 2.15×10^{-4} Gg/ha form BRRI dhan 29. But the incorporation of three additional numbers of drainage i.e. 3 IDWR to CFWR, the emission rate was dramatically reduced and it was estimated that, the methane emission was only 29% for both types of rice cultivars compared to CFWR. By adding another drainage i.e. 4 IDWR, emission rate was reduced to 22% for BRRI dhan 28 and around 20% for BRRI dhan 29 compared to CFWR. Emission reduction rate was estimated higher in BRRI dhan 29, because it produced more microbial decomposable materials. When these materials are exposed to anaerobic condition for a longer period, then it emits more methane compared to BRRI dhan 28. So, by reducing the length of anaerobic condition by providing drainage, reduction was higher from BRRI dhan 29. In 5 IDWR, methane emission was 0.22×10^{-4} Gg/ha and 0.28×10^{-4} Gg/ha from BRRI dhan 28 and BRRI dhan 29, respectively. That means incorporation of five number of intermittent drainage to the CFWR fields, almost 85% methane emission has reduced from BRRI dhan 28 and this figure was around 87% for BRRI dhan 29. Moreover, by applying additional single drainage to the previous condition, the methane emission from both rice cultivars was reduced up to 93% (Figure 5.11).

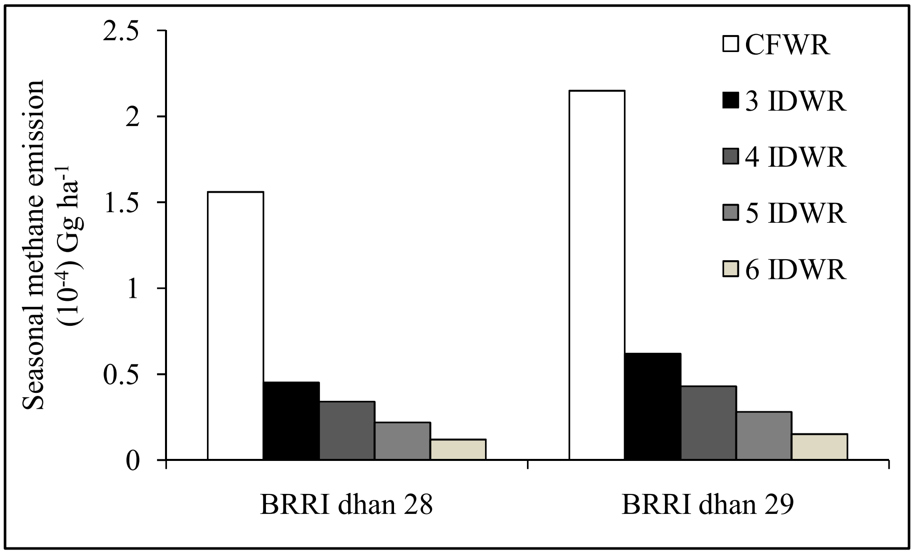

Figure 5.11: Effects of different water management practices on the rate of methane emission form irrigated rice fields

5.5.8 Effects of direct seeding

Direct seeding is one kind of crop establishment practice which could significantly reduce the rate of methane emission form the Boro rice fields. It also reduces the water requirements of land preparation. In this practice, at first farmers only plow their land and then rice is seeded directly into the soaked fields. So, like transplanting, it does not require any kind of irrigation at the very beginning of seeding. The first irrigation has to be incorporated at 20 days after seeding (DAS). Thus, it reduces around 17% of methane emission form those 20 days. Besides, after providing the first irrigation, all the methods of AWD are followed over the rest of the growth stage. Hence, for reducing the methane emission rate it is more effective than that of AWD.

Figure 5.12 shows the comparison of rate of methane emission from different agricultural practice i.e. CFWR, AWD and direct seeding. For both the BRRI dhan 28 and BRRI dhan 29, direct seeding is the most effective method to reduce the emission rate. By applying AWD (with 6 numbers of AID) in the CFWR, methane emission form Boro rice fields was reduced by 93%. Where as, by applying direct seeding the emission reduction rate was estimated at around 94% from the rice cultivars.

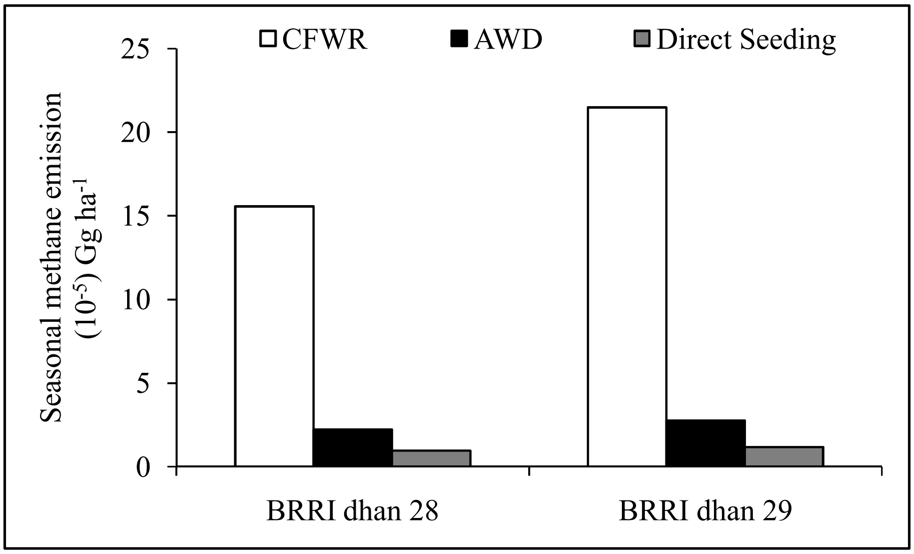

Figure 5.12: Effects of direct seeding on the rate of methane emission form irrigated rice fields

5.5.9 Effects of transplanting date

Date of transplantation of rice can play an active role in the rate of methane emission. This is because, methane emission is regulated by the daily average temperature, especially the maximum temperature. Emission rates accelerate with the increasing of daily maximum temperature (Section 5.5.1). It also depends upon the growth stages of rice plant when the temperature is increased. Reproductive stage of rice plant with increasing temperature emits more methane to the atmosphere (Section 2.3.4).

Traditionally, local farmer transplant Boro rice at the middle of January. In reproductive stage, the extremeness of methane emission was found. So, the maximum emission has observed at mid March to mid April. At that period, country faced excessive daily maximum temperatures which positively stimulate the rate of methane emission from irrigated rice fields. From that perspective, the effects of two different shifting modes i.e. shifting of 7 days EFTP (Earlier from the Traditional Practice) and shifting of 14 days EFTP on methane emission were calculated through the model. All of the revised dates for model analysis are shown in the Table 5.9.

Table 5.9: Different mode of shifting and subsequent date of transplanting, harvesting, flooding (irrigation), drainage and OM application

Mode of shifting	Transplanting Date (D/M/Y)	Harvesting Date (D/M)	Flooding Date (D/M)	Drainage Date (D/M)	OM application Date (D/M/Y)
7 days EFTP	08/01/2010	08/05	08/01	25/04	01/01/2010
14 days EFTP	01/01/2010	01/05	01/01	18/04	24/12/2009

The model result regarding the effects of traditional practice and two different shifting modes on the rate of methane emission form irrigated Boro rice fields in the study area are given in the Figure 5.13. In traditional practice, BRRI dhan 28 emit around 1.6×10^{-4} Gg/ha and BRRI dhan 29 emit 2.2×10^{-4} Gg/ha of methane. But, shifting of 7 days EFTP and shifting of 14 days EFTP reduced the emission rate at 6% and 19% respectively for BRRI dhan 28. On the other hand, those two modes of shifting reduced about 9% and 18% of methane emission over the traditional practice for BRRI dhan 29.

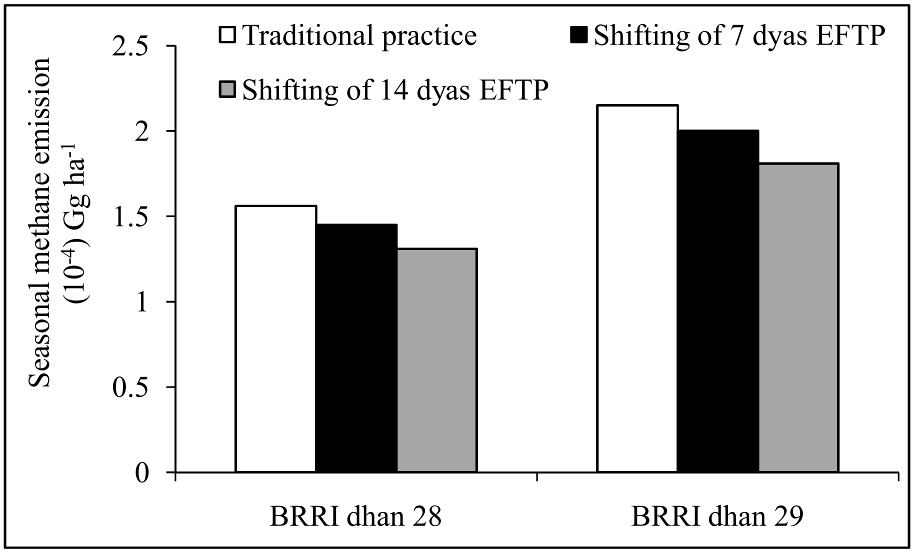

Figure 5.13: Effects of shifting of transplanting date on the rate of methane emission form irrigated Boro rice fields

5.6 Future Projection of Methane Emission form Boro Rice Cultivation

Projected rate of methane emission from continuously flooded rice (Boro rice) fields has been estimated for two different years 2030 and 2050 based on CH4MOD2.5 model. To run the model for the estimation, all of the input parameters except atmospheric temperature (daily maximum and minimum), precipitation and concentration of CO_2, were the same as in 2009 and the data for the projections are given in Table 3.4. The projections were carried out for two Boro rice cultivars i.e. BRRI dhan 28 and BRRI dhan 29 under three different water management practices i.e. CFWR, 3IDWR and 5IDWR.

Figure 5.14 shows the projected rate of methane emission form irrigated Boro rice fields in 2030 and 2050 under the different water management practices. The higher rate of emission was estimated from BRRI dhan 29 for both the years 2030 and 2050 compared to BRRI dhan 28. If it considered that in future, the water management practice for Boro rice cultivation will be continued under CFWR, then country will emit around 653 Gg of methane (213 Gg from BRRI dhan 28 and 440 Gg form BRRI dhan 29) in 2030 and the rate will be around 906 Gg (296 Gg from BRRI dhan 28 and 610 Gg form BRRI dhan 29) in 2050. The rate of emission will be approximately 39% and 56% higher in 2030 and 2050, respectively than the rate of emission in 2009.

But, considering the recent adoption trend of AWD practiced in the farmers' fields, the rate of emission scenarios will be dramatically changed (i.e. reduced) for 2030 and 2050. By applying 3 additional drainages into the CFWR, emission rate will be reduced around 64% for both the years 2030 and 2050. Similarly, incorporation of 5 additional drainages into the CFWR, around 84% methane emissions will be reduced for the years 2030 and 2050.

The most notice worthy observation was that, in 2009, the annual methane emission from Boro rice cultivation under CFWR was estimated as 397 Gg. However, under the changing water management practices, emission rate will be lowered by 40% and 17% (from the 3IDWR practice) in 2030 and 2050, respectively. In the same way, emission rate will be lowered by 73% and 63% (from the 5IDWR practice) in 2030 and 2050, respectively compared to the rate estimated in 2009 under CFWR practices.

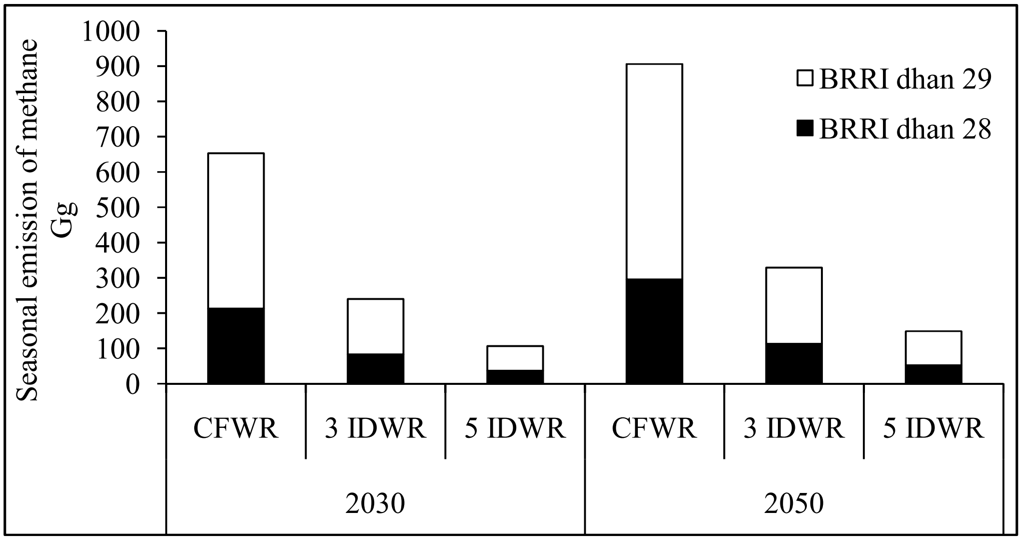

Figure 5.14: Projection of rate of methane emission from irrigated Boro rice fields under different water management practices in future

Figure 5.15 and Figure 5.16 show the trend of daily maximum temperature in 2030 and 2050, respectively. Higher rate of emission in 2050 was only because of higher atmospheric temperature and concentration of atmospheric CO_2 (532 ppm) compared to 2030 (452 ppm) as shown in Table 3.4.

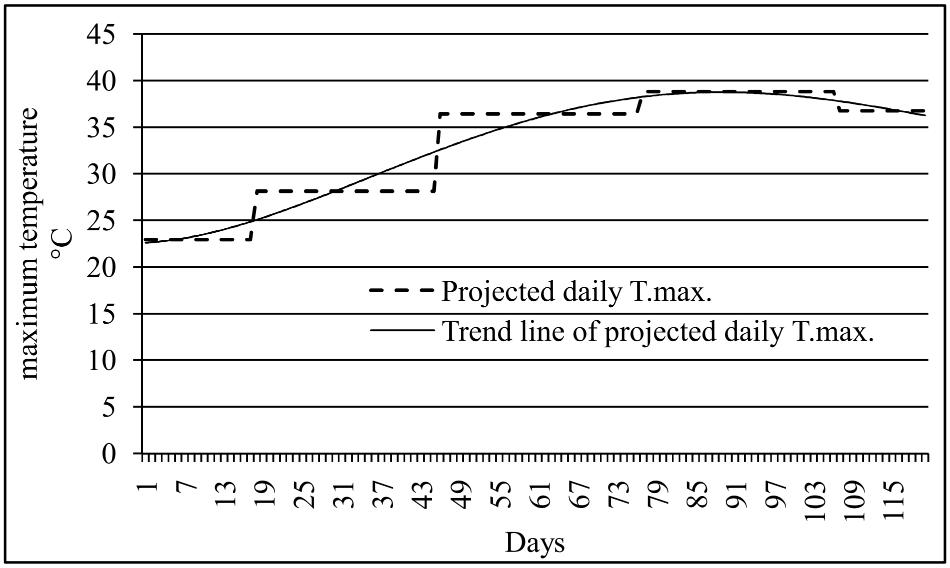

Figure: 5.15: Trend analysis of daily maximum temperature in 2030

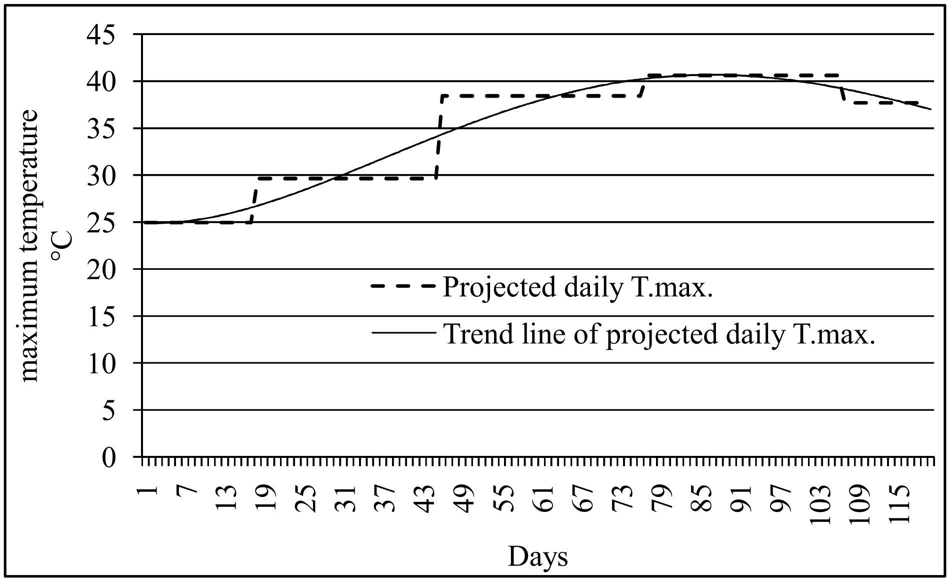

Figure: 5.16: Trend analysis of daily maximum temperature in 2050

5.7 Assessment of Possible Mitigation Measures and Farmers Perception

Identifying and assessing of possible adaptation options to control and reduce the rate of methane emission from the irrigated Boro rice fields were exclusively studied. The possible mitigation options that were applied in different countries were identified by literature review and then the local farmers' perception towards those options were assessed. From the FGD, the most effective and applicable mitigation measures for the study area were changing of rice cultivars, AWD, application of N_2 fertilizer, shifting of transplanting date, direct seeding and application of bio-fertilizer.

5.7.1 Changing of rice cultivars

As rice cultivars is an active factor that influence the rate of methane emission form irrigated rice fields (Figure 5.10), so changing to varieties which emit lower methane could be an effective mitigation measure. In the study area, local farmer traditionally cultivate BRRI dhan 29 which emit highest rate of methane compared to the other existing varieties (Figure 5.1). Not only in study area but also in the entire country, its adoption rate is almost 60% or higher. Farmer's prefer this variety due to its higher yields (from 5.5 t/ha to 6 t/ha) and longer straw height (around 95 cm) compared to BRRI dhan 28.

From farmer’s point of view, they are willing to change their existing variety if they are given a rice variety which has the basic properties like higher yield, lower duration of cultivation period, moderate plant height and lesser tiller number (if possible) (PRRI, 2011).

The first priority of local farmer is the yields and they are not interested to sacrifice the yield although it is proportionate to the rate of methane emission.

The second priority is given to duration which also influences to reduce the emission rate. Local farmer prefer lesser duration because through it they are able to reduce the frequency and number of irrigation into the rice fields and thus save the cost of irrigation. Another important reason for choosing lower duration of rice variety is that, through such a variety they are able to protect their crop form the uncertainty of natural calamities. Most of the rice in the study area is harvested within the month April. From the geo-climatic context of country, April has the greater likelihood of occurrence of extreme climatic events (droughts, hail storm etc.). Lower duration of rice cultivars also encourage the reduction of methane emission (Section 5.5.6).

The third priority is to have moderate plant height. Plant height is vital, from methane emission reduction point of view as well as form farmer’s perspective. Local farmers do not prefer the rice cultivars which are short. This is because the rice straw is used as the basic food for the survival of their livestock.

So, if it is possible to develop rice varieties which have the aforementioned basic properties, the local farmers are willing to select those rice cultivars and help to reduce the rate of methane emission form irrigated Boro rice fields.

5.7.2 Application of nitrogen fertilizer

Reduction and control of application rate of N_2 fertilizer to the rice fields could be other measures to mitigate the rate of methane emission form irrigated Boro rice fields (Section 5.5.3). Farmer traditionally uses chemical fertilizer to stimulate the growth of rice plants. As methane emission from rice fields is the net consequences of several processes including CH_4 production, oxidation and transportation from soil to the atmosphere, application of N_2 fertilizer directly or indirectly affect all of these processes (Xie et al. 2010). Mainly two basic form of N_2 fertilizers are available, one is

Nitrate based and another is Ammonium based. Although Nitrate based fertilizer are capable of significantly reducing the rate of methane emission but it is rarely applied due to its low efficiency and subsequent emission of N_2O (Cai et al. 2007). Ammonium based fertilizer (commonly known as urea) is most frequently used all over the world as well as in the study area. The application of urea into the rice fields increases the availability of methanogenic substrates (i.e. methane producing bacteria) and competency of the transportation of emission and thus enhance the rate of methane production and emission (Schimel, 2000; Zheng et al. 2006).

According to BARC (2005), the recommended dose of N_2 fertilizer application for the study area is around 110 kgN/ha. But during the FGD, it was observed that the local farmers have reduced the rate of application of N_2 fertilizer by about 18%. They mentioned that the use of more urea over the recommendation dose has reduced the fertility of their land. Moreover, their perception is that, higher use of urea may enhance the pest attack. A portion of farmer replied that, last couple of years they have got more yield from their rice fields compared to others without using of urea. They use compost fertilizer instead of urea.

Innovation of Leaf Color Chart (LCC) by IRRI has also helped in the reduction of urea application rate. LCC is easy to use and is an inexpensive diagnostic tool to monitor the deficiency and requirements of N_2 fertilizer to rice plants. DAE has provided LCC to every farmer at the study area and also provide the required information and knowledge to use LCC. LCC is the combination of four distinguished color chart regarding to the color of rice plant at different scenarios and recommended dose of urea application have also been assigned for every color so that local farmer is able to understand it easily. On the other hand, by the extensive training program, they are now using pellet (guti) urea rather than the granular urea. Pellet urea has a lesser chance of loss during the incorporation into the rice fields and thus increases the rice yields.

All of these initiatives and the higher adoption of LCC for reducing the rate of urea application into the rice fields would ultimately help to contribute to the reduction mechanism of methane emission form irrigated rice fields.

5.7.3 Application of AWD

Practice of AWD instead of continuous flooding in the irrigated Boro rice fields is the most effective and efficient method to mitigate the rate of emission of methane from rice fields (Section 5.5.7). In the context of present and future water scarcity for agricultural purposes, CFWR is not effective way of Boro cultivation, as it declines the water productivity. Several studies suggested that, CFWR is nothing but the waste of water. For getting the maximum yield, retaining a certain level of water in the rice fields over the whole growing period is not required.

In AWD, several alternate wetting (irrigation) and drying (drainage) phases are adopted. It is uncomplicated to apply and local farmer can easily adopt and cope with this kind of practice. For implementing AWD, farmers are required to monitor the depth of water table installing unsophisticated perforated cylindrical pipes into their fields.

The potentiality of methane production from the rice fields is related to the period of stagnant water over the crop season. So, by practicing AWD, 5 to 6 number of added aeration can reduce the emission rate (around 87 to 93%) through modifying the anaerobic reaction to aerobic reaction (Figure 5.11). Thus the method is significant for reducing the methane emission from irrigated rice fields.

During the FGD, it was observed that, the local farmers in the study area are aware of the effectiveness and importance of application of AWD. DAE has provided extensive training to local farmers regarding the implementation of AWD. The farmers are interested to practice AWD in their rice fields as it reduces their input cost without any effect on yields. In areas where the pricing for irrigation water is time based, farmers can save a significant amount of money by implementing AWD. But, in the area where the pricing system is area based the farmers pay a certain or fixed amount of money for the irrigation over the whole Boro cultivation period, pump manager can maximize their profit by reducing the numbers of irrigation. So, to implement AWD in the farmer’s fields, time based pricing of irrigation should be established. During the discussion with the farmers some management related problems for the implementation of AWD into their rice fields were pointed out.

Local farmers told that, one of the major obstacle for practicing AWD in their rice fields is the uncertainly of electricity supply. After an intermittent drainage, when farmers need to re-irrigate their fields, at that time if there is the shortage of electricity, then farmers suspect that a certain yield reduction would occur due to inability of providing required irrigation. So, the farmers do not want to take the risk of reducing their yields by practicing AWD.

Another important impediment for implementing AWD in the rice fields is the low conveyance efficiency. The canals for providing irrigation are unlined. So loss of water is huge. Farmers in the low land informed that, when the machine manager distribute irrigation water to the high land fields, their land become flooded due to the loss of water. Thus, it is difficult for lowland framers to adopt AWD. So, by providing proper training and by improving and ensuring the efficiency of current management practices, it would be possible to implement the AWD in their rice fields.

5.7.4 Direct seeding

Direct seeding could be another alternative to reduce the methane emission rate form the Boro rice fields. Form the discussion in Section 5.5.8 it is observed that, by applying direct seeding practice over the CFWR, emission rate could be reduced by up to 94% for a particular rice variety (BRRI dhan 29). During FGD, the major problem of direct seeding identified by the local farmers was vigorous growth of the weeds. Before the introduction of the transplanting technique, local farmers were habituated to direct seeding for rice cultivation. In transplanting all the rice seedlings are transplanted in the fields by maintaining an alignment (hill to hill and row to row). While, in direct seeding no alignment can be maintained. So, weed management is quite difficult in direct seeding rather than the transplanting. Farmers required more time as well as more money to manage the weeds and hence are reluctant to adopt direct seeding.

5.7.5 Application rate of organic amendments

Mircobial decomposition of organic matters under complete anaerobic condition for certain period of time is the key source and mechanism for production and emission of methane form irrigated Boro rice fields. So, source control or reduction could be one of the effective strategies to mitigate the emission rate.

In the traditional practice, animal manure i.e. cow dung and rice straw which is retained in the fields after harvesting of Aman are the main sources of organic amendments for Boro cultivation. During FGD, local farmers told that, after harvesting of Aman they retained rice straw with a height of at least 18 cm (7 inches) and this straw acts as an organic fertilizer for Boro cultivation. There is a problem in retaining lesser amount of rice straw (i.e. <18 cm) in the fields although it can be an effective measure to OM source reduction. They have mentioned that, the height of rice straw (i.e. 18 cm) is continuously submersed under water over the whole cultivation period in their current water management practice. For this reason, the outer part of rice straw is coated by various kinds of algae and turn to yellowish to blackish or dark in greenish color. Livestock, especially cow, never wants to take those blackish or greenish portions of rice straw as food. So, it is impractical to reduce the height of retained rice straw although rice straw emits high rate of methane emission among the different OM used in the farmers' fields (Figure 5.8) .

From the Section 5.5.5 it was calculated that, reduction of application rate of farm manure is another option to control the source of organic amendments. During the FGD it was found that, local farmers apply approximately 600 kg/ha (dry weight) of cow dung into their Boro rice fields. But this rate is gradually decreasing due to the scarcity of livestock. So, some of the local farmers have already reduced the application rate. But, if they reduce the rate of FM then the urea application rate should be enhanced to maintain the yield.

5.7.6 Shifting of transplanting date

Shifting of transplanting date from the traditional practice is another mitigation measure to reduce the rate of methane emission from irrigated Boro rice fields (Section 5.5.9). The main mechanism that acts behind this mitigation approach is that, as temperature is directly proportional to the rate of emission, shifting of transplanting date minimizes the effects of extreme temperature on methane emission.

During the FGD, there was a mixed reaction from the local farmers regarding shifting date as the mitigation option of methane emission. Most of them think that it will be better for their yields because the peak demand of electricity occurs at mid March to whole April and this is also the time for peak demand for Boro rice cultivation. So, due to lack of electricity for irrigation purposes, they lose a significant portion of their yields. Shifting of transplanting date, 14 days earlier over the traditional practice may resolve the problem.

However, the shifting date by 14 days was not acceptable to some of the local farmers. This is because, they think that the maximum temperature is not high enough for flowering of Boro rice if the Boro rice is transplanted 14 days earlier. Farmers of high land are more enthusiastic to shift their transplanting date. But the problem for low land farmers is that, after the harvesting of Aman they want their land to dry up for Boro cultivation. So, within 1st January (i.e. shifting date of transplanting), the overall drying process of their land may not be completed. In that case, they can try with other option i.e. shifting of 7 days EFTP if possible.

Chapter 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

In this study, an attempt was made to identify the present status of methane emission from Bangladesh as it is one of the leading rice producing countries of the world. For choosing and implementing the best emission mitigation strategies, it was essential to have a sound knowledge regarding the factors which potentially affect the emission pattern and rate from rice fields. So, after such analyses, some possible mitigation measures have been proposed on the basis of local farmers' perceptions.

The methodology proposed by IPCC (2006) was used to calculate the country average annual rates of methane emission from both the Aman (calculation was carried out for BR 11 variety) and Boro (calculation was carried out for BRRI dhan 28 and BRRI dhan 29) rice cultivation. Aus were not considered in the study because its adoption rate is not significant and it is not subjected to stagnant irrigation water.

From the findings it was observed that, from the year 2000 to 2009, the average annual rate of methane emission from both seasons was around 1071 Gg. Variety specific annual emission rate was found for BR 11 as around 48.3 mg m^{-2} d^{-1} and for both the BRRI dhan 28 and BRRI dhan 29 as around 197.5 mg m^{-2} d^{-1}. Due to the limitations in methodology, emission rate was observed as same for BRRI dhan 28 and BRRI dhan 29.

By using CH4MOD model average annual emission rate was found as around 464 Gg in which 83% methane came from Boro rice and rest of 17% from Aman rice. Emission rate for BRRI dhan 28 was 27.72% lower than (69.92 mg m^{-2} d^{-1}) that of BRRI dhan 29 (96.73 mg m^{-2} d^{-1}). However, the lowest emission rate was found for BR 11 variety as 20.4 mg m^{-2} d^{-1}.

Using IPCC methodology, US-EPA provided a projected value of methane emission from all sorts of rice cultivation in Bangladesh. The projected figure was 850 Gg and 918 Gg for the year 2005 and 2010 respectively. On the other hand, this figure was estimated as 1087 Gg in 2005 and 1146 Gg in 2009 by using IPCC (2006) methodology. From the model the estimated emissions were 471 Gg and 496 Gg for the same years.

If all the model parameters remain same, methane emission from irrigated rice fields is positively affected by atmospheric temperature, specially the maximum temperature. Emission rate was enhanced at 2% for BRRI dhan 28 and 2.5% for BRRI dhan 29 by an increase of 18 ppm of atmospheric CO_2 from the year 2000 to 2009. But this rate was increased to 13% and 16% for BRRI dhan 28 and BRRI dhan 29, respectively when both the temperature and CO_2 are increased simultaneously. This happened because, increase of CO_2 increases the decomposable organic carbon and the increase of temperature increases the rate of decomposition.

Effects of nitrogen (urea) fertilizer on methane emission was studied by considering three different application rates of 90, 100 and 110 kgN/ha and it was found that, increasing of 10 kg of N fertilizer per ha, enhanced the emission rate at 0.15% for BRRI dhan 28 and 0.21% for BRRI dhan 29.

Emission rate was estimated to be higher in the sandy soil compared to clayey soil. If all the model parameters remain fixed, with 10% increase of proportion of sand, the rate of emission was increased at 21% in Boro season.

Among the selected four different types of OM, the rate of emission was estimated to be highest for rice straw, followed by residual decomposed OM, green manure and farm manure. Incorporation of residual decomposed OM, green manure and farm manure instead of rice straw, reduced the methane emission by 15%, 20% and 40% (in BRRI dhan 28), and by 13%, 18% and 38% (in BRRI dhan 29), respectively. Model results show that, for every 10% decrease in existing application rate of FM with 10% increase of N_2 fertilizer up to 30%, the emission rate was reduced gradually by 10%, 19% and 27% for both rice varieties.

Methane emission rate was found to be 27% higher in BRRI dhan 29 compared to BRRI dhan 28 only because of having higher plant height, growth duration and yield.

In BRRI dhan 29, methane emission can be reduced by 71%, 80%, 87% and 93% by applying 3, 4, 5 and 6 IDWR, respectively instead of CFWR. For BRRI dhan 28, the corresponding values are 71%, 78%, 85% and 92%, respectively.

In direct seeding, land preparation is not required and first irrigation is applied 20 DAS. So, direct seeding method with 6 AID reduces methane emission by 94%.

Shifting of 7 days and 14 days EFTP over the traditional transplanting date reduced the emission rate by 6% and 19%, respectively from BRRI dhan 28 and 9% and 18% respectively, from BRRI dhan 29.

From the model projection, under the CFWR, the country will emit around 653 Gg (213 Gg from BRRI dhan 28 and 440 Gg form BRRI dhan 29) and 906 Gg (296 Gg from BRRI dhan 28 and 610 Gg form BRRI dhan 29) of methane from irrigated Boro rice in the year 2030 and 2050, respectively. These are approximately 39% and 56% higher than the present emission. Incorporation of 3 and 5 additional drainages instead of CFWR, emission rate will be reduced around 64% and 84% for both the year 2030 and 2050. Under the changing water management practices, emission rate will be lowered by 40% and 17% (from the 3IDWR practice) in 2030 and 2050, respectively. Similarly, emission rate will be lowered by 73% and 63% (from the 5IDWR practice) in 2030 and 2050, respectively compared to the rate estimated in 2009 under CFWR practices.

Through the extensive literature review several mitigation options were identified. During the FGD with local farmers, changing of rice cultivars, AWD, application of N_2 fertilizer, shifting of transplanting date, direct seeding and change in application rate of OMs was found as the possible mitigation measures for the study area.

Local farmer's are willing to change their existing high emission variety (BRRI dhan 29) if they are given a variety which has the similar properties like higher yield, lower duration of cultivation period, moderate plant height and lesser tiller number.

During the FGD it was also found that, local farmer have reduced the application rate of N_2 fertilizer into the rice fields by 18% compared to recommended dose by BARC (2005). Due to the negative consequences of N_2 fertilizer, local farmer are interested to use compost fertilizer. They use pellet urea instead of granular form of urea. LCC by IRRI has also helped for the reduction of urea application rate at the study area.

AWD was the most effective mitigation option. With the help of DAE, local farmers have already practiced AWD into their rice fields as it can save their irrigation cost without sacrificing the yields. But they pointed out that, uncertainty of electricity supply, non-availability of irrigation water, less conveyance efficiency and inadequate knowledge and training are the major difficulties to its wider adoption.

Direct seeding is also effective in reducing methane emission but the only problem is weed management. Farmers required more time as well as more money to manage the weeds.

Local farmers are already habituated to reduced application rate of FM in the rice fields due to the scarcity of food for livestock.

Farmers believe that, shifting of transplanting date may help to protect their crops from damage from natural disaster that occur at the later part of growing season. But the shifting of transplanting date is only applicable for high lands.

6.2 Recommendations

On the basis of the findings of the model study, the following recommendations have been made:

- In the study, only Tangail district was considered as the representative of country total methane emission. So, in future incorporation of more districts from other agro-hydrologic regions should be taken into consideration.
- For the projection of future rate of methane emissions, only A1B emission scenario was considered. So, in future other scenarios could be considered to predict the future methane emission rate.
- In the study, estimation of methane emission from Bangladesh was calculated by using the monthly average temperature (maximum and minimum) and precipitation data of BMD. So, use of daily average data in the future study would provide a better scenario of methane emission.
- Soil temperature is an important factor that can affect the rate of methane emission from irrigated rice fields. Thus, investigation of how soil temperature regulates the emission rate should be taken into consideration.

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Appendix A

Calculation of straw yield and rate of straw retained in the fields for selected three rice varieties (BR 11, BRRI dhan 28 and BRRI dhan 29)

a. For BR 11

Straw yield calculation:

$$\text{HI} = \frac{\text{. y (d w)}}{\text{n (d w) S y(w)}}$$

$$0.42 = \frac{\text{. t n h}}{\text{. t h+ S y(dw)}}$$

$$\text{Straw yield (dry weight)} = \frac{\text{. t n h}}{\text{.}} - 3.62\ \text{ton ha}$$

$$= 4.999\ \text{ton ha} \quad \cong 5\ \text{ton ha}$$

Percent of straw retained after harvesting:

$$\frac{17.78\ \text{cm}}{115\ \text{cm}} \times 100 = 15.46\%$$

Computation of straw retained in the field:

$$5\ \text{ton ha} \quad \times 15.46\% = 0.773\ \text{ton ha}$$

b. For BRRI dhan 28

Straw yield calculation:

$$\text{HI} = \frac{\text{y (d w)}}{\text{n (d w) S y(w)}}$$

$$0.42 = \frac{\text{. t h}}{\text{. t n + S y(dw)}}$$

$$\text{Straw yield (dry weight)} = \frac{\text{. t h}}{\text{.}} - 4.5\ \text{ton ha}$$

$$= 6.21\ \text{ton ha}$$

Percent of straw retained after harvesting:

$$\frac{17.78\ \text{cm}}{90\ \text{cm}} \times 100 = 19.755\% \cong 20\%$$

Computation of straw retained in the field:

$$6.21\ \text{ton ha} \quad \times 20\% = 1.24\ \text{ton ha}$$

c. For BRRI dhan 29

Straw yield calculation:

$$\text{HI} = \frac{\text{y (\quad d w \quad)}}{\text{n \quad (\quad d w \quad) \quad S \qquad y(\qquad w \quad)}}$$

$$0.49 = \frac{\text{. \quad t \qquad h}}{\text{. \quad t \quad n \quad + S \qquad y(\quad dw \quad)}}$$

$$\text{Straw yield (dry weight)} = \frac{\text{. \quad t \qquad h}}{\text{.}} - 5.5\ \text{ton ha}$$

$$= 5.72\ \text{ton ha}$$

Percent of straw retained after harvesting:

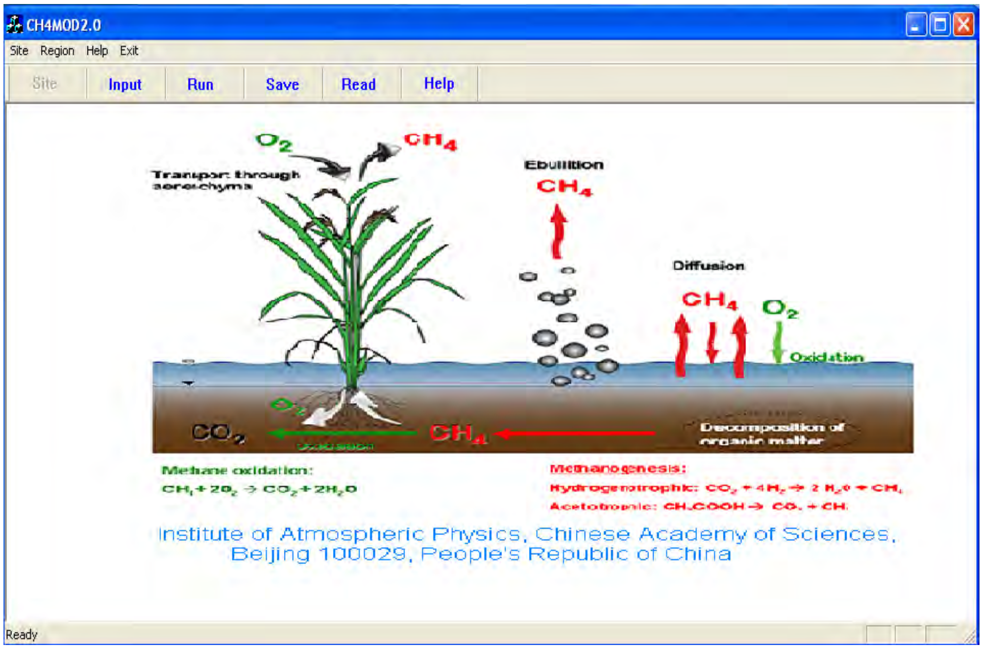
$$\frac{17.78\ \text{cm}}{95\ \text{cm}} \times 100 = 18.72\% \cong 20\%$$

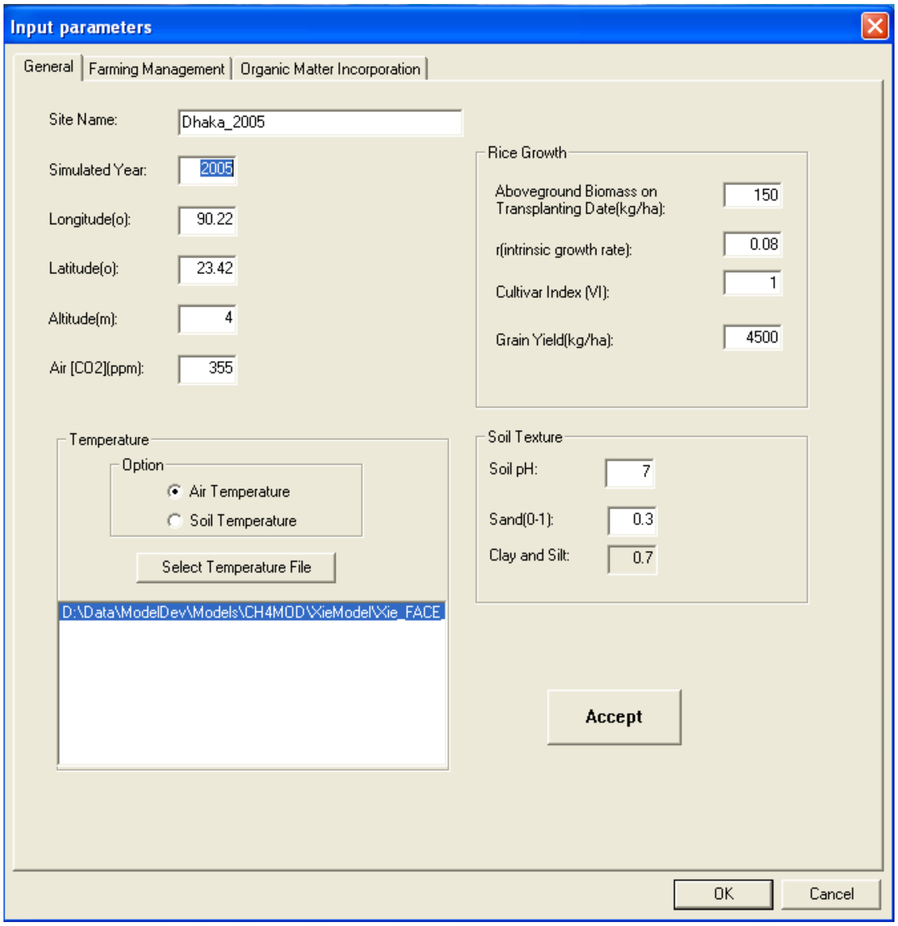
Computation of straw retained in the field:

$$5.72\ \text{ton ha} \quad \times 20\% = 1.14\ \text{ton ha}$$

Appendix B

Screen shots of the model input parameters





Site Name: Dhaka_2005

Simulated Year: 2005

Longitude(o): 90.22

Latitude(o): 23.42

Altitude(m): 4

Air [CO2](ppm): 355

Rice Growth

Aboveground Biomass on Transplanting Date(kg/ha): 150

r(intrinsic growth rate): 0.08

Cultivar Index (VI): 1

Grain Yield(kg/ha): 4500

Temperature

Option

● Air Temperature

○ Soil Temperature

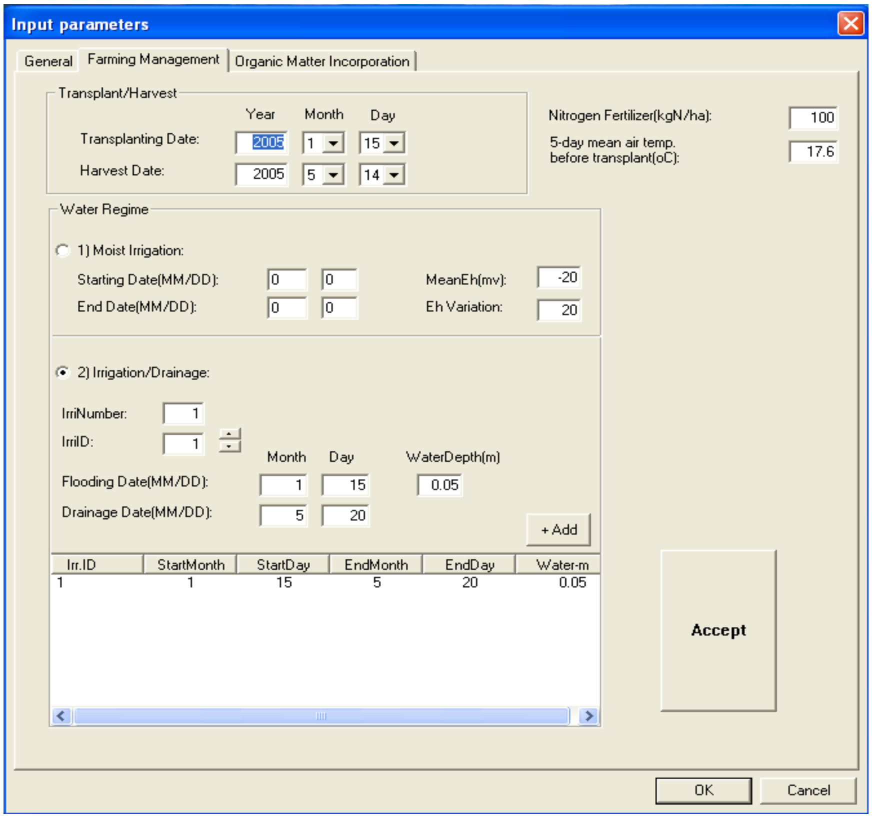
D:\Data\ModelDev\Models\CH4MOD\XieModel\Xie_FACE

Soil Texture

Soil pH: 7

Sand(0-1): 0.3

Clay and Silt: 0.7



Transplant/Harvest

	Year	Month	Day
Transplanting Date:	2005	1	15
Harvest Date:	2005	5	14

Nitrogen Fertilizer(kgN/ha): 100

5-day mean air temp. before transplant(oC): 17.6

Water Regime

○ 1) Moist Irrigation:

Starting Date(MM/DD): 0 0

End Date(MM/DD): 0 0

MeanEh(mv): -20

Eh Variation: 20

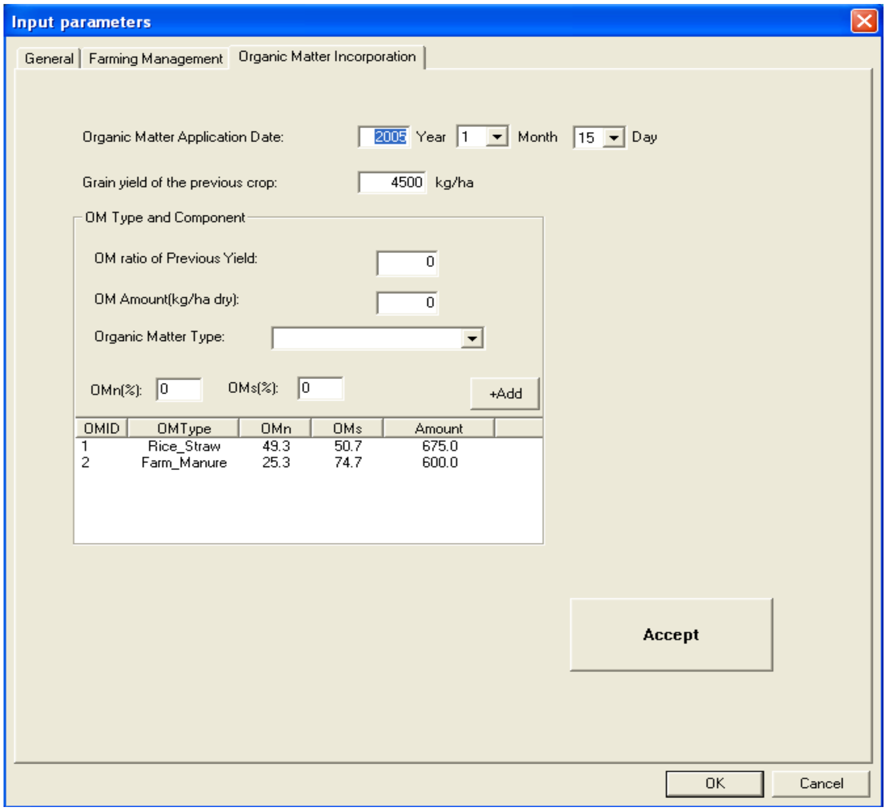
● 2) Irrigation/Drainage:

IrriNumber: 1

IrriID: 1

	Month	Day	WaterDepth(m)
Flooding Date(MM/DD):	1	15	0.05
Drainage Date(MM/DD):	5	20	

Irr.ID	StartMonth	StartDay	EndMonth	EndDay	Water-m
1	1	15	5	20	0.05



Organic Matter Application Date: 2005 Year 1 Month 15 Day

Grain yield of the previous crop: 4500 kg/ha

OM Type and Component

OM ratio of Previous Yield: 0

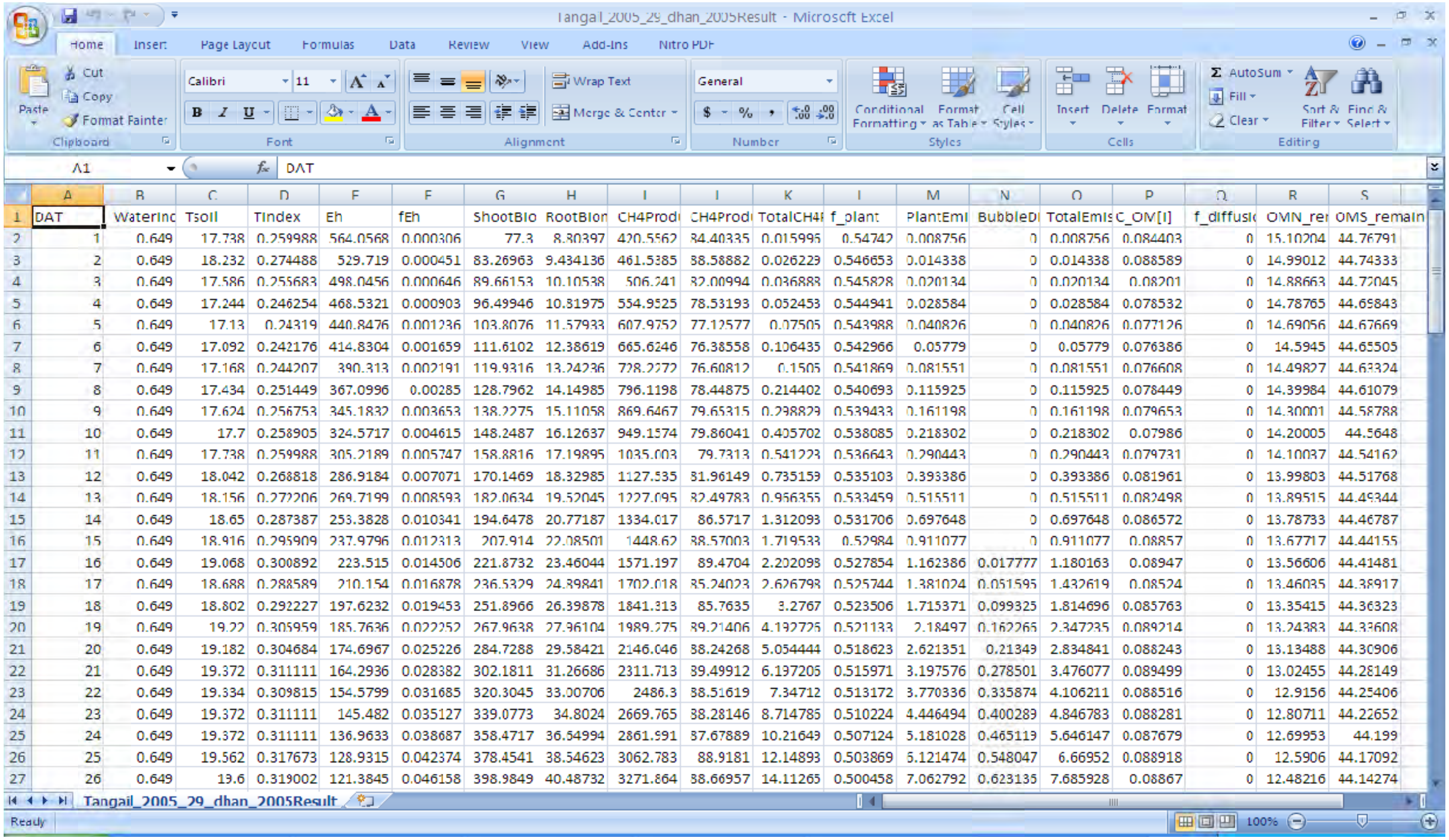
OM Amount(kg/ha dry): 0

Organic Matter Type:

OMn(%): 0 OMs(%): 0

OMID	OMType	OMn	OMs	Amount
1	Rice_Straw	49.3	50.7	675.0
2	Farm_Manure	25.3	74.7	600.0

Snapshots of the output of the model



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	DAT	WaterInc	Tsoil	TIndex	Eh	fEh	ShootBio	RootBion	CH4Prodi	CH4Prodi	TotalCH4I	f_plant	PlantEmi	BubbleDi	TotalEmis	C_OM[I]	f_diffusi	OMN_rer	OMS_remain
2	1	0.649	17.738	0.259988	564.0568	0.000306	77.3	8.30397	420.5562	84.40335	0.015995	0.54742	0.008756	0	0.008756	0.084403	0	15.10204	44.76791
3	2	0.649	18.232	0.274488	529.719	0.000451	83.26963	9.434136	461.5385	88.58882	0.026229	0.546653	0.014338	0	0.014338	0.088589	0	14.99012	44.74333
4	3	0.649	17.586	0.255683	498.0456	0.000646	89.66153	10.10538	506.241	82.00994	0.036888	0.545828	0.020134	0	0.020134	0.08201	0	14.88663	44.72045
5	4	0.649	17.244	0.246254	468.5321	0.000903	96.49946	10.81975	554.9525	78.53193	0.052453	0.544941	0.028584	0	0.028584	0.078532	0	14.78765	44.69843
6	5	0.649	17.13	0.24319	440.8476	0.001236	103.8076	11.57933	607.9752	77.12577	0.07505	0.543988	0.040826	0	0.040826	0.077126	0	14.69056	44.67669
7	6	0.649	17.092	0.242176	414.8304	0.001659	111.6102	12.38619	665.6246	76.38558	0.106435	0.542966	0.05779	0	0.05779	0.076386	0	14.5945	44.65505
8	7	0.649	17.168	0.244207	390.313	0.002191	119.9316	13.24236	728.2272	76.60812	0.1505	0.541869	0.081551	0	0.081551	0.076608	0	14.49827	44.63324
9	8	0.649	17.434	0.251449	367.0996	0.00285	128.7962	14.14985	796.1198	78.44875	0.214402	0.540693	0.115925	0	0.115925	0.078449	0	14.39984	44.61079
10	9	0.649	17.624	0.256753	345.1832	0.003653	138.2275	15.11058	869.6467	79.65315	0.298829	0.539433	0.161198	0	0.161198	0.079653	0	14.30001	44.58788
11	10	0.649	17.7	0.258905	324.5717	0.004615	148.2487	16.12637	949.1574	79.86041	0.405702	0.538085	0.218302	0	0.218302	0.07986	0	14.20005	44.5648
12	11	0.649	17.738	0.259988	305.2189	0.005747	158.8816	17.19895	1035.003	79.7313	0.541223	0.536643	0.290443	0	0.290443	0.079731	0	14.10037	44.54162
13	12	0.649	18.042	0.268818	286.9184	0.007071	170.1469	18.32985	1127.535	81.96149	0.735159	0.535103	0.393386	0	0.393386	0.081961	0	13.99803	44.51768
14	13	0.649	18.156	0.272206	269.7199	0.008593	182.0634	19.52045	1227.095	82.49783	0.956355	0.533459	0.515511	0	0.515511	0.082498	0	13.89515	44.49344
15	14	0.649	18.65	0.287387	253.3828	0.010341	194.6478	20.77187	1334.017	86.5717	1.312093	0.531706	0.697648	0	0.697648	0.086572	0	13.78733	44.46787
16	15	0.649	18.916	0.295909	237.9796	0.012313	207.914	22.08501	1448.62	88.57003	1.719533	0.52984	0.911077	0	0.911077	0.08857	0	13.67717	44.44155
17	16	0.649	19.068	0.300892	223.515	0.014506	221.8732	23.46044	1571.197	89.4704	2.202098	0.527854	1.162386	0.017777	1.180163	0.08947	0	13.56606	44.41481
18	17	0.649	18.688	0.288589	210.154	0.016878	236.5329	24.89841	1702.018	85.24023	2.626798	0.525744	1.381024	0.051595	1.432619	0.08524	0	13.46035	44.38917
19	18	0.649	18.802	0.292227	197.6232	0.019453	251.8966	26.39878	1841.313	85.7635	3.2767	0.523506	1.715371	0.099325	1.814696	0.085763	0	13.35415	44.36323
20	19	0.649	19.22	0.305959	185.7636	0.022252	267.9638	27.96104	1989.275	89.21406	4.192726	0.521133	2.18497	0.162265	2.347235	0.089214	0	13.24383	44.33608
21	20	0.649	19.182	0.304684	174.6967	0.025226	284.7288	29.58421	2146.046	88.24268	5.054444	0.518623	2.621351	0.21349	2.834841	0.088243	0	13.13488	44.30906
22	21	0.649	19.372	0.311111	164.2936	0.028382	302.1811	31.26686	2311.713	89.49912	6.197205	0.515971	3.197576	0.278501	3.476077	0.089499	0	13.02455	44.28149
23	22	0.649	19.334	0.309815	154.5799	0.031685	320.3045	33.00706	2486.3	88.51619	7.34712	0.513172	3.770336	0.335874	4.106211	0.088516	0	12.9156	44.25406
24	23	0.649	19.372	0.311111	145.482	0.035127	339.0773	34.8024	2669.765	88.28146	8.714785	0.510224	4.446494	0.400289	4.846783	0.088281	0	12.80711	44.22652
25	24	0.649	19.372	0.311111	136.9633	0.038687	358.4717	36.54994	2861.591	87.67889	10.21649	0.507124	5.181028	0.465119	5.646147	0.087679	0	12.69953	44.199
26	25	0.649	19.562	0.317673	128.9315	0.042374	378.4541	38.54623	3062.783	88.9181	12.14893	0.503869	6.121474	0.548047	6.66952	0.088918	0	12.5906	44.17092
27	26	0.649	19.6	0.319002	121.3845	0.046158	398.9849	40.48732	3271.864	88.66957	14.11265	0.500458	7.062792	0.623135	7.685928	0.08867	0	12.48216	44.14274