Chapter 1

Greenhouse gas emission from rice: Issues, monitoring and budgeting

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There has been a drastic increase in the atmospheric concentration of carbon dioxide (CO_2) methane (CH_4), nitrous oxide (N_2O) and other green house gases (GHGs) since the industrial revolution. The atmospheric concentration of CO_2 has increased from 280 parts per million by volume (ppmv) in 1750 to 379 ppmv in 2005 and is currently increasing at the rate of 1.9 ppmv yr^{-1} (IPCC, 2007). Atmospheric CH_4 concentration has increased from about 715 to 1774 parts per billion by volume (ppbv) in 2005 over the same period and is increasing at the rate of 7 ppbv yr^{-1} (IPCC, 2007). Similarly, the atmospheric concentration of N_2O has increased from about 270 ppbv in 1750 to 319 ppbv in 2005 and is increasing at the rate of 0.8 ppbv yr^{-1} (IPCC, 2007). The current radiative forcing of these trace gases (GHGs) is 1.46 W m^{-2} for CO_2, 0.5 W m^{-2} for CH_4 and 0.15 W m^{-2} for N_2O (IPCC, 2001). This anthropogenic enrichment of GHGs in the atmosphere and the cumulative radiative forcing of all GHGs have led to an increase in the average global surface temperature of 0.74°C since the late 19th century, with the current warming rate of 0.13°C $decade^{-1}$ (IPCC, 2007). The observed rate of increase of the global mean temperature is in excess of the critical rate of 0.1°C $decade^{-1}$ beyond which the ecosystems cannot adjust. These changes may affect the soil organic carbon (SOC) pools, dynamics, and structural stability and may disrupt cycles of water, carbon (C) and nitrogen (N) resulting into adverse impacts on biomass productivity, biodiversity and the environment.

The natural as well as anthropogenic activities have serious effects on the ever increasing concentrations of CO_2, CH_4, N_2O and other GHGs in the atmosphere. The heat-trapping properties of these aforesaid GHGs are well established. Greenhouse gases differ in their warming influence (radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. Changes in the atmospheric concentrations of GHGs alter the energy balance of the climate system which leads to subsequent climate change. They affect the absorption, scattering and emission of radiation within the atmosphere and at the earth's surface. The resulting positive or negative changes in energy balance due to these factors, known as radiative forcing, is used for comparison of warming or cooling influences on global climate. Atmospheric concentrations of GHGs increase when emissions are larger than removal processes. These GHGs have profound impact on global climatic changes resulting into increase in ambient temperature which is likely to affect agriculture (IPCC, 2007). Although uncertainty exists as to how the earth's climate responds to these GHGs, there has been a significant rise in global temperatures. It is anticipated that increasing concentrations of GHGs are likely to accelerate further the rate of climate change. Scientists are expecting that the average global surface temperature could rise by 1.4°C-5.8°C by 2100 AD with significant regional variations (IPCC, 2007).

Agriculture can play an important role in mitigating three GHGs: CO_2, CH_4, and N_2O, having global warming potentials (GWP) 1, 24.5 and 320, respectively for a 100 year time horizon (IPCC, 2007). Plants absorb CO_2 from the atmosphere and extract some carbon for use in developing plant tissues. Oxygen (O_2) and CO_2 are released back into the atmosphere. When the plant dies, the carbon in the plant tissues is converted back to CO_2 if decomposition is aerobic, to CH_4 if decomposition is anaerobic, or remains in the soil as soil organic matter (SOM). Aerobic decomposition takes place where decaying plant material is either on the surface or close to it and exposed to alternating wet and dry periods. Anaerobic decomposition releases CH_4 and takes place in fields that are flooded for extended periods, such as those used for paddy rice. Rice farming plays a significant source of GHGs. Anaerobic decomposition in rice fields results in the release of substantial amounts of CH_4 into the atmosphere. The interactive nature of carbon and nitrogen cycles in rice fields demands a consideration of the other GHGs, namely, N_2O and CO_2, in view of full GWP accounting. Rice is the major cereal crop feeding two-thirds of the global population. Rice, the most important cereal after wheat, can be grown to extreme limits of temperature, day length, salinity and water supply. But, rice cultivation contributes to the emission of GHGs of concern (e.g., CH_4 and N_2O) to the atmosphere which affect adversely the atmospheric chemistry and the environment. Projected changes in global climate are expected to affect many marginal and fragile ecosystems. Rice crop is also likely to be affected by the impending changes in the environment

Rice occupies one-third of the world's crop land planted to cereals and provides 30-60% of the calories consumed by nearly three billion people (Guerra et al., 1998). Rice production is an important part of Asia's economy. But competitive market, day by day hike in input cost, ever increasing demand from all quarters and intensive agriculture are posing concern to its productivity and sustainability. A comprehensive understanding of how the physical environment affects rice yield is the key to improve agronomic production and its sustenance. In Asia, rice is the major food crop, and about 80% of it is grown under flooded conditions (Zou et al., 2005). Rice is grown in different environments ranging from tropical to temperate regions with varying climatic, edaphic, and biological conditions which naturally affect the rates of CO_2, CH_4 and N_2O emissions. These trace gas flux exchanges between paddy fields and the atmosphere is also greatly influenced by cultivation practices and field management, such as ploughing, stable manure amendment, seeding or transplanting of rice, water management, harvest, treatment of harvest residuals.

Carbon dioxide exchange between terrestrial ecosystems and the atmosphere is one of the key processes that affect atmospheric CO_2 concentration. In order to assess the role of terrestrial ecosystem in the global CO_2 budget at present, and to predict its changes in the future under global warming, long-term observation of CO_2 exchange has been done in various ecosystems in the world. Carbon di-oxide is an extremely important greenhouse gas as it contributes to increasing radiative forcing and thus to climate change as well as other negative impacts. These relationships are highly complex due to many feedbacks and interactions (Haszpra et al., 2008). Global atmospheric concentration of this gas increased about 35% from the pre-industrial time upto 2005. Worldwide variation in CO_2 concentrations is determined by the balance between sources and sinks (Vinogradova et al., 2007). Photosynthesis and natural respiration processes are linked to the superimposed effects of other factors such as fossil fuel combustion for energy purposes (specifically energy and transport sectors) and land use changes (Artus et al., 2009). Carbon di-oxide concentrations are also influenced by atmospheric processes in the boundary layer which affect their transport and dispersion (Ramonet et al., 2010). Variations in sources, biological processes, meteorological features of the boundary layer and geographical features of the area of interest are the main controlling factors for variability in CO_2 levels. By 2020, the ambient CO_2 concentration will reach 400 ppmv and by 2050, tropospheric CO_2 concentration is predicted to increase by 50%. But, on the other hand, CO_2 has a significant impact on crop photosynthesis, agricultural production and productivity.Rice soils that are flooded for long periods in the year tend to accumulate soil organic carbon (SOC),even with complete removal of the aboveground plant biomass (Bronson et al., 1997). Significant inputs of C and N are derived from the biological activity in the soil-floodwater system, and conditions are generally more favorable for the formation of conserved SOC (Olk et al 1998, Kirk and Olk 2000). In China, it is estimated that the current C sequestration rate in irrigated rice cultivation is 12 Tg C year^{-1} and that these systems have induced a total enrichment of SOC storage of about 0.3 Tg C (Pan et al., 2003)

Methane has strong infra-red and heat absorption band characteristics and worldwide its increasing concentration in the atmosphere is believed to contribute towards change in atmospheric chemistry as well as global warming (IPCC, 2007). Methane is presently the second most important GHG accounting for 15-20% of the anthropogenic radiative forcing. The major sources of CH_4 production are the rice paddies, ruminants, landfills, natural wet lands and sediments (Zhu et al., 2007). Tropospheric CH_4 has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Although the tropospheric CH_4 is increasing continuously, increase of CH_4 emission has started to decline during the past two decades (IPCC, 2007). Among the sources of CH_4 irrigated rice fields are estimated to contribute between 6-8% (Tseng et al., 2010) of the total 410-660 million tons year^{-1} emitted globally (Tseng et al., 2010). Flooding of irrigated rice fields produces anaerobic soil conditions which are conducive to the production of CH_4 (Neue, 1993).

Nitrous-oxide is generated by the microbial transformation of N in soils and manures, and is often enhanced where available N exceeds plant requirements, especially under wet conditions (Oenema et al., 2005). The rice paddies act as sources of major N_2O emission upon nitrogenous fertilizer (e.g., urea) application. Nitrogenous fertilizer appears to be the single most important factor controlling N_2O emission from flooded rice fields. Actually N_2O is produced in considerable amounts both in upland (aerobic) and wetland (predominantly anaerobic) soils especially under N-fertilizer dependent agriculture. Wide variation in N_2O production exists in different rice soils.

Therefore, it is now evident that the flooded rice paddies are one of the most important sources of CH_4 and N_2O emission. The attendant global climatic change as a result of increased ambient temperature may, in turn, adversely affect rice cultivation and rice-based production systems. But, rational and judicious optimization of agricultural management practices may result into partial mitigation of the greenhouse effects by curbing CO_2, CH_4 and N_2O emissions to atmosphere during rice cultivation. These management practices, if properly and wisely adopted, would substantially cut down and limit these GHGs emissions from rice and rice-based production systems to atmosphere at the national and global scales. But, the uncertainties in the GHG fluxes from rice fields are due to complexity and variation of the sources, agricultural management practices, limitations in the measurement equipment and the methodology used to quantify the emissions. In order to compile the full GHG balance (for characterization and budgeting) and to understand the processes that affect this balance during rice production, long-term measurements are needed covering all three gaseous species. Hence, close frequency of monitoring/ sampling, proper calibration of monitoring devices and sound precision and accuracy of measurement instruments for quantification of GHGs from rice fields are essential in this regard.

Issues

Global increases in CO_2 concentrations are primarily due to fossil fuel use, with land-use change providing another significant but smaller contribution. Carbon dioxide (CO_2) is released largely from microbial decay of plant litter and soil organic matter. Agriculture through the process of photosynthesis absorb CO_2 from atmosphere, there is very small net emission of CO_2 due to agiculture unless it is done by clearing forest land a kind of practice found in part of India and else where. However, the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. Methane is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, from stored manures and from rice grown under flooded conditions. On the other hand, the major source of increase in more than one third in N_2O concentration is due to human activity, primarily agriculture. Nitrus oxide is generated by the microbial transformation of N in soils and manures and nitrogenous fertilizers, and is often enhanced where available N exceeds plant requirements, especially under wet conditions (Oenema et al., 2005). Thus agricultural GHG fluxes are complex and heterogeneous in source and of nature, but the active management of agricultural systems offers possibilities for mitigation.

Agriculture accounted for an estimated emission of 5.1 to 6.1 Gt CO_2-eq year^{-1} in 2005, almost 10-12% of total global anthropogenic emissions of GHGs. Methane contributes 3.3 Gt CO_2-eq year^{-1} and N_2O 2.8 Gt CO_2-eq year^{-1}. Of global anthropogenic GHG emissions in 2005, agriculture accounts for about 60% of N_2O and about 50% of CH_4. Despite large annual exchanges of CO_2 between the atmosphere and agricultural lands, the net flux is estimated to be approximately balanced, with CO_2 emissions around 0.04 Gt CO_2 year^{-1} only. Globally, agricultural CH_4 and N_2O emissions have increased by nearly 17% from 1990 to 2005, an average annual emission increase of about 60 Mt CO_2-eq year^{-1}.

The present GHG budget of agricultural fields could be different from previously estimated values because the pattern of land use changed drastically in the last couple of decades. Thus, it becomes evident to detect the current GHG budget from agricultural land. Quantification of GHGs exchanges between terrestrial ecosystems and atmosphere are strongly needed to make comprehensive budgeting of those GHGs. From this point of view, it is pertinent to mention about FLUX NETWORK activities worldwide. AmeriFlux, AsiaFlux, ChinaFlux, KoreaFlux, CARBOEUROPE, NITROEUROPE have been launched on the flux observation project at various types of ecosystems including agricultural fields. Long-term GHG budget monitoring studies are covered under these FLUX NETWORK activities.

Longterm CO_2 measurement data series are continuously being collected and analyzed at the Mauna Loa High Altitude Observatory for about last 50 years (Hofmann et al., 2009). Additionally the Global monitoring Division of the National Oceanic and Atmospheric Administration (NOAA) is also measuring CO_2 and other GHGs in a global network (Conway et al., 2008; Tans, 2011). The United Nations Framework Convention on Climate Change (UNFCCC) records all the GHGs concentrations and sets the global warming potentials of all the naturally/ anthropogenically produced GHGs for a particular time span. There is also a worldwide network of measuring stations promoted by the World Meteorological Organization (WMO) which provides reliable informations. Intergovernmental Panel on Climate Change (IPCC) is the main parent body which publishes the recent and updated concentration of GHGs, their emission scenarios, projected emission trends in the coming future and mitigation options on a periodic interval. Although uncertainty exists regarding the magnitude and flux data of those GHGs worldwide depending on the sources and management practices, which necessitates for proper monitoring and quantification of the trace gas fluxes from different rice production systems.

Rice is grown in the Asian counties during two distinct seasons namely the dry and the wet season. The dry season, from January to April, tends to produce higher yields than the wet season, from July to October. Generally rice thrives in a flooded ecosystem. This condition enriches the nutrients available for crop's growth, allowing farmers to reap abundant harvests. The dark side is that this flooded ecosystem emits mostly CH_4 as well as N_2O depending upon the agricultural management practices that contribute to global climate change. Mid-season drainage or intermittent irrigation, which prevents the development of soil reductive conditions, is considered to be an effective option for mitigating CH_4 emissions from rice fields (Yagi et al 1997). However, under such situations the increased N_2O emissions may offset the benefit gained by reduction of CH_4 emission. There is a trade off between N_2O and CH_4 emission depending upon the water level, level and type of fertilisers applied, soil organic matter and state of residue retention or incorporation. Similarly, for saving water during rice production, alternate wetting and drying (AWD) and growing of aerobic rice in well-drained, nonpuddled and non-saturated soils are becoming popular. But the environmental impacts of these methods are yet to be established. Alternate wetting and drying maintains the basic features of flooded rice fields and keeps the potential for higher production intact. Although this practice reduces CH_4 emissions, it can potentially increase the release of CO_2 and N_2O, two important GHGs. Aerobic rice systems similarly entail drastic changes in C and N emissions and canopy temperature that contribute to global warming and aggravate heat stress for the rice plants. Although the consequences for the sustainability of rice fields remain unknown, it is customary to assess the use of AWD and aerobic rice as an option to mitigate the adverse effects of climate change and, at the same time, to reduce emissions.

Research work should be focused to find out the potential avenues to reduce GHGs emissions from rice production with relatively low opportunity costs and increased productivity.These technologies should be tested and validated in the farmers field. Adapting technologies to local conditions is necessary involving farmers, extension agents and research institutions in technology design and dissemination. Technically, CH_4 reduction from irrigated rice ecologies and CO_2 and N_2O reduction from upland (aerobic) rice production systems could be a promising strategy to mitigate GHG emissions in line with the idea of certified emission reductions (CERs) introduced in the Kyoto Protocol. According to this regulation farmers can receive payments from a private or public institution in an unindustrialized country for reducing GHG emissions in line with the idea of Carbon Credit Compliance. In the next step, a designated panel of the UNFCCC can approve CERs that can be used by the purchasing institution as part of its required contingent of emission savings. Increasing food production is an absolute necessity for ever increasing human population and improved resource use efficiencies are imperative to achieving this goal. Therefore, definite provisions should be there for adopting CERs in different rice production systems keeping in mind the food security and GHG mitigation by computing net GWP savings based on food production targets.

Monitoring technologies for study of greenhouse gas emissions from rice fields

Flooded rice paddies and aerobic rice production systems have important roles on GHG budget. The rice crops uptake atmospheric CO_2 due to photosynthesis and the soil microorganisms along with crop emit CO_2 during respiration. Lowland submerged rice paddies are major CH_4 source and upland conditions enriched with nitrogenous fertilizers mostly emits N_2O and CO_2. These sink/source strength capacity depends on the management practices. Therefore, GHG emissions from rice fields of different rice production systems demands continuous, precise and accurate monitoring and their proper quantification for budgeting. Thus long-term GHGs flux observation studies in different rice ecosystems are necessary. Several technologies are available for monitoring of GHG emission from agriculture. Real time accurate and precise monitoring of GHGs emissions from rice paddy ecosystems are possible with the help of open and or closed path eddy covariance (EC) technique, static chambers method and by soil and plant canopy chambers using infrared gas analyzer (IRGA).

Numerous micrometeorological measurements of CO_2 flux have been made in paddy fields since the 1960s, and the eddy covariance method was often applied after the 1980s (Miyata et al., 2000). However, most of those studies involved short-term measurements lasting a few days to a few weeks. A long-term CO_2 flux measurement study covering two consecutive growing seasons at a rice field in Texas, USA, using the relaxed eddy accumulation method. However, as mentioned before, differences in cultivation practices and field management affect the CO_2 budgets of paddy fields.

Trace gas fluxes can be measured using chamber or micrometeorological methods (Wesely & Hicks, 2000). Chamber methods integrate over small areas, from < 1 m^2 (Husted, 1993) up to 64 m^2 (Galle et al., 1994) and can alter local environmental conditions. General errors caused by chambers are related to perturbations of the natural conditions at the sampling site, modifications of the microclimate, pressure-induced gas flows in open chambers and inhibiting effects of concentration build-up in closed chambers (Lapitan et al., 1999). On the other hand, micrometeorological methods do not interfere with processes of gas exchange between the surface source and the atmosphere and are ideally suited for continuous flux measurements (Denmead, 1995).

Eddy covariance systems using tunable diode laser absorption spectroscopy are now becoming available for automated measurement of CH_4 and N_2O fluxes from agriculture (Kim et al., 1999). However, these systems are costly. In contrast, combining profile measurements of CH_4 concentrations with eddy covariance measurements of energy fluxes (denoted as flux-gradient method) (Miyata et al., 2000) is less costly than the laser based spectroscopy method for the measurement of CH_4. In contrast to the conventional chamber technique (Khalil et al., 2008), the flux-gradient method can measure the CH_4 flux without physically disturbing the sample area. There have been several attempts to use measured CH_4 effluxes at specific sites to arrive at estimates for the global emission from rice paddies. The results vary greatly, from 20 to 100 Tg yr^{-1} (Zou et al., 2005). Field experiments have shown that the large variability in CH_4 emissions is both spatial and temporal as well as seasonal and diurnal (Sass et al., 1991). Although a large number of field measurements of CH_4 effluxes have been made in the past decade, their spatial coverage is still poor, and extrapolating the results from point measurements to the global scale involves many uncertainties (Cao et al., 1995).

FIGURE 1. *Eddy covariance system*

Eddy covariance technique-based net ecosystem carbon dioxide exchange

Long term measurements of CO_2 flux have been carried out in various ecosystems in the world, especially in forest ecosystems as they are believed to be the most influential terrestrial ecosystems in the global CO_2 budget (Carrara et al., 2003). On the other hand, non-forest ecosystems *viz.* grasslands, wetlands and agricultural fields have also been observed because they contribute to regional and global CO_2 budgets (Tsai et al., 2006). The eddy covariance (EC) technique is widely employed as the standard micrometeorological method to monitor fluxes of CO_2, water vapour and heat, which are bases to determine CO_2 and heat balances of land surfaces (Fig. 1) (Aubinet et al., 2000). The EC technique has become the most important method for measuring trace gas exchange between terrestrial ecosystems and the atmosphere (Smith et al., 2010). The direct, continuous measurement of carbon, water and energy fluxes between vegetated canopies or biosphere and the atmosphere can be obtained with minimal disturbance to the vegetation using this sophisticated research tool. It can represent a large area of land at the ecosystem than the typical plot area (Lalrammawia et al., 2010) for a short period or even for several years. It has become the backbone for bottom up estimates of continental carbon balance from hourly to inter annual time scales (Reichstein et al., 2005).

The EC technique is based on high frequency (10-20 Hz) measurements of wind speed and direction as well as CO_2 and water concentrations at a point over the canopy using a three-axis sonic anemometer and a fast response infrared gas analyzer (Fig. 2) (Aubinet et al., 2003). Assuming perfect turbulent mixing, these measurements are typically integrated over periods of half an hour building the basis to calculate carbon and water balances from daily to annual time scales. Apart from three-axis sonic anemometer and fast response infra-red gas analyzer several other sensors are attached to the EC unit for measurement of some auxiliary parameters namely, relative humidity, air temperature, incoming radiation, net radiation, photosynthetic photon flux density, photosynthetically active radiation, precipitation, soil temperature, soil moisture, soil heat flux etc. Eddy covariance flux towers are currently operational worldwide covering different climate conditions; land use and land cover (Baldocchi et al., 2001).

FIGURE 2. *Sensors of eddy covariance system*

In Asia, EC flux measurements were conducted in Japan (Miyata et al., 2005;), Korea (Moon et al., 2003), Bangladesh (Hossen et al., 2011), Philippines (Alberto et al., 2009), Thailand (Pakoktom et al., 2009), China (Xiu E et al., 2007), Taiwan (Tseng et al., 2010) and India (Bhattacharyya et. al., 2011) to monitor seasonal, annual and or inter-annual variations in CO_2 fluxes in rice fields (Fig. 3). In rice paddy ecosystems it can be employed to measure net ecosystem CO_2 exchange (NEE) or net ecosystem production (NEP). The technique uses the covariance between rapid fluctuations in vertical wind speed measured with a three-dimensional ultrasonic anemometer and simultaneous measurements of the rapid fluctuations in the CO_2 concentration as measured by a fast-response IRGA. A positive covariance between vertical fluctuations and the CO_2 mixing ratio indicates the net CO_2 transfer into the atmosphere from plant-soil system and a negative value indicates net CO_2 absorption by the vegetation (Moncrieff et. al., 1997). Net ecosystem exchange is measured continuously by EC technique applying proper correction terms and gap-filling, if required. Net ecosystem exchange is further partitioned into gross primary production (GPP) and ecosystem respiration (RE). Ecosystem respiration is extrapolated from night time fluxes to daytime by using temperature response functions and afterwards GPP is calculated by subtracting RE from NEE (Fig.4) (Bhattacharyya et. al. 2011).

FIGURE 3. *Eddy covariance system in rice field*

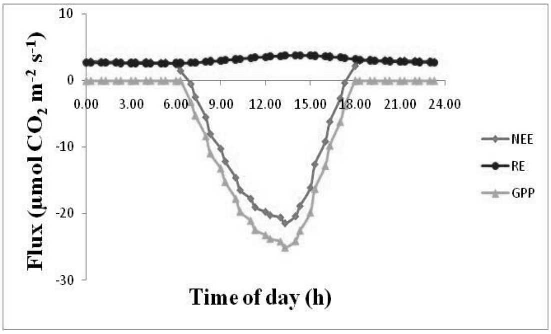

FIGURE 4. *Net ecosystem exchange, gross primary production and ecosystem respiration of rice field in Cuttack*

Eddy covariance system continuously monitors and stores half-hourly and hourly CO_2 flux (NEE) data, using which carbon footprint analysis of specific ecosystem can be characterized precisely. As because plants exchange most of their carbon as CO_2, eddy flux-derived NEP is an ideal variable for C budgeting from local to regional scales. However, over time, net C fluxes are good proxies for ecosystem total biomass stock change (Baldocchi, 2003). The flux networks use eddy covariance-based measurement system for assessing regional sectoral carbon budgets. There are hundreds of eddy covariance towers monitoring continuously and organized in global network including forests, grasslands and croplands (Smith et al., 2010).

FIGURE 5. *Soil respiration chamber in rice field*

FIGURE 6. *Soil respiration chamber and temperature sensor placed on soil*

Measurement of soil carbon dioxide efflux and plant respiration by infra-red gas analyzer-based soil respiration chamber or canopy chamber

Infra-red gas analyzer -based field measurement is the most widely used technique for assessing soil respiration flux rates (Fig. 5 & 6). The method (for measuring soil CO_2 efflux employing IRGA) estimates the increase in enclosed chamber CO_2 concentration over a specified time (Luo & Zhou, 2006). Different IRGA-based measurements of soil respiration or soil CO_2 efflux depends on differences in IRGA and chamber design (cuvette area and volume, use of collars, presence or absence of chamber vents), measurement parameters (enclosure time, chamber flow rate, purge parameters) and CO_2-flux algorithms (with or without moisture and temperature correction). These effects are also dependent on soil type and vegetation in which the measurements are being undertaken (Mills et al., 2011). Moreover, the chambers always affect the object being measured, with each chamber type having its own limitations (Davidson et al., 2002).

The three major chamber techniques used widely for measuring soil CO_2 efflux are closed static chamber (non-steady-state non-through-flow chamber), closed (non-steady-state through-flow chamber) and open dynamic chamber (steady-state through-flow chamber). In case of non-steady-state chambers (both the through-flow and non-through-flow types) the CO_2 efflux is determined from the rate of concentration increase in an isolated chamber, which has been placed on the soil surface for a known period of time. In case of steady-state chambers CO_2 efflux is calculated from the difference between CO_2 concentration at the inlet and the outlet of the chamber.

When a non-steady-state chamber is placed on the soil and the concentration in the chamber headspace starts to change, rising concentration within the chamber may influence the CO_2 efflux from the soil by altering the natural soil concentration gradient (Livingston & Hutchinson, 1995). Pressure anomalies caused by placing the chamber on the soil surface may also disturb the CO_2 concentration gradient in the soil. In case of steady-state chambers, pressure differences between the inside and outside of the chamber can generate mass flow of CO_2 from the soil into the chamber (Lund et al., 1999).

In a dynamic open chamber method, air passes through the chamber and gas analyser and is then evacuated; the efflux of CO_2 from the soil (Sr) covered by the chamber is obtained as a function of the difference in CO_2 concentration between air entering and leaving the chamber (Eq. 1) (Smith et al., 2008).

$$Sr = \Delta c\,(f / A) \text{ -------- } 1$$

Where, c is the difference in CO_2 mass fraction in the incoming and outgoing air streams; f is the gas flow rate through the chamber and A is the surface area covered by the chamber (Nakayama, 1990). The difference in CO_2 concentration is usually measured by an IRGA.

If a closed chamber is placed on the soil, the concentration of CO_2 respired from the soil will build up inside the chamber and this enrichment can be used to estimate the efflux from the soil. This method is the basis of many of the successful commercial designs in the market today. The soil efflux can be expressed by (Eq. 2):

$Sr = (\Delta c / \Delta t) V / A$ -------- 2

Where, c is the CO_2 concentration increment in the chamber in the time interval t; V is the volume of air within the chamber and A is the soil surface area covered by the chamber. The CO_2 content of a sample taken at discrete intervals can be measured by alkali absorption or by gas chromatography (GC) (Castro et al., 1994).

Plant respiration in case of rice is measured by the canopy chamber, enclosing the canopy and stand for specified time and then measuring the liberated CO_2 due to respiration with the help of IRGA.

Measurement of emission of methane and nitrous oxide fluxes by chamber and eddy covariance method

Methane and N_2O emissions are measured through the manual or automatic closed chamber measurements and or employing eddy covariance technique. These chamber measurements are widely used as they are easy to apply in field trials with multiple small plots. The manual chamber measurements (Fig. 7) are usually made very frequently (2-3 days interval) where as automatic chamber measurements allow continuous and frequent measurements.

FIGURE 7. *Chamber measurement for methane and nitrous oxide emission studies*

From the static chambers (equipped with small pulse pump for homogeneous mixing of air sample inside the chamber over specific time period) air samples are collected in tedlar® bags at 0, 15 and 30 minute intervals. Samples are then collected by syringe for analysis of CH_4 and N_2O by gas chromatography using flame ionisation and electron capture detectors, respectively (Das et al., 2011).

Automated chamber methods are expected to produce more reliable results rather than manual chamber measurements as diurnal variations in fluxes of GHGs (CH_4, N_2O) are captured. Automatic chamber measurements may suffer from underestimation of fluxes due to chamber effects on soil moisture conditions during rainfall (Yao et al., 2009).

An integrated eddy covariance system associated with trace gas analyzer (TGA), a tunable diode laser analyzer, can measure trace gas fluxes *viz.* CH_4, N_2O, NO_2, NH_3 and CO_2. Laser spectroscopy also provides new measurement techniques to measure CH_4 and N_2O concentrations at high temporal resolution (10 Hz), appropriate for eddy covariance flux calculations (Hendriks et al., 2008). Eddy covariance measurements of CH_4 and N_2O using lead salt tunable diode laser (TDL) spectrometers and quantum cascade laser (QCL) spectrometers are also possible (Neftel et al., 2007).

In spite of considerable efforts to quantify CH_4 and N_2O emissions from rice fields, the estimates of this source strength are still attached to major uncertainties. Intensive field measurement campaigns have clearly revealed the complex interaction of water regime as the major determinant of emissions on the one hand and several other influencing factors on the other. Given the diversity of rice production systems, reliable upscaling of CH_4 and N_2O source strengths requires a high degree of differentiation in terms of management practices and natural factors. Modeling approaches have been developed to simulate their emissions as a function of a large number of input parameters, namely, modalities of management as soil and climate parameters.

Budgeting

Agriculture accounts for about 15% of the global emission of GHGs. Carbon dioxide, CH_4 and N_2O budget in rice fields are affected by structure and dynamics of anaerobic and aerobic conditions in the soil and due to other agricultural management practices. Methane emission increases under continuous flooding while N_2O is primarily emitted in pulses after fertilization and strong rainfall events. Various rice growing environments show wide spatio-temporal variability in CH_4 emission. Land use practices and N-fertilizer applications greatly influence N_2O emission from soil.

Carbon dioxide flux exhibited a clear diurnal pattern ranging from -38 to 10 µmol CO_2 m^{-2} s^{-1} during full heading stage of rice (70-79 Days after transplanting) in 2006 boro rice growing season in Bangladesh (Hossen et al., 2007). The total C budget integrated over the cropping period showed that the net ecosystem CO_2 exchange (NEE) in flooded rice fields (-258 g C m^{-2}) was about three times higher than that of aerobic rice fields (-85 g C m^{-2}) in IRRI, Philippines (Alberto et al., 2009). The daily CO_2 flux values in rice ecosystem in Taiwan ranged from -17.03 µmol CO_2 m^{-2} s^{-1} to 12.85 µmol CO_2 m^{-2} s^{-1}. Fluxes of CO_2 were always positive during night hours, average value being 2.76 µmol CO_2 m^{-2} s^{-1}; whereas during the daytime the flux was found to be negative with an average value of -1.22 µmol CO_2 m^{-2} s^{-1} (Tseng et al., 2010). Spatial and temporal variation of CO_2 fluxes were seen in different Asian countries (Table 1).

TABLE 1. *Comparison of mean carbon dioxide fluxes measured by eddy covariance system in Asian countries.*

Location	CO_2 flux (µmol m^{-2} s^{-1})	Fertilizer and water management	Duration
Japan (day/night) (Miyata et al., 2000)	-3.81 (-16.95/9.32)	Chemical fertilization and drained soil condition	1-week (a month before heading stage of the crop)
Japan (day/night) (Miyata et al., 2000)	-7.63 (-19.57/4.32)	Chemical fertilization and flooded soil condition	1-week (a month before heading stage of the crop)
Taiwan (day/night) (Tseng et al., 2010)	0.71 (-1.22/2.76)	Chemical fertilization and drained soil condition	1-month (from heading to maturity stage of the crop)

Methane emission varied from 14 to 375 mg m^{-2} d^{-1} in most rice growing areas in the world. Annual global estimation of CH_4 emission from flooded rice fields accounted for 7.08 Tg based on the biomass (Sinha, 1995). In Thailand, Wassmann et al. (2000) estimated 99 Kg CH_4 ha^{-1} $season^{-1}$ from deepwater rice fields. Average CH_4 emission rates ranged from 11-364 mg m^{-2} d^{-1} from rice fields of Beijing, China (Wang et al., 2000). It is affected by water regimes, soil amendments, cultivars and type of fertilizers used. In India the mean CH_4 emission from rice fields ranged between 3.5-4.2 Tg yr^{-1} (Parashar et al., 1996). An irrigated continuously flooded rice paddy system showed a CH_4 emission value of 4-26 mg m^{-2} h^{-1} and 0.7-4.7 Gg ha^{-1} per cropping season of 75 days (Adhya et al., 1994). Bhatia et al. (2004) estimated 4.7 Tg yr^{-1} CH_4 emission from the Indian paddy fields with the highest emission of 1.379 Tg yr^{-1} from the irrigated rice fields. Methane emission from lowland rice preceded by an upland crop in dry season was 12.52-13.09 g CH_4 m^{-2} day^{-1}, which was significantly lower than the CH_4 emission from a lowland rice-rice system (Adhya et al., 2000a). Adhya et al. (2000b) reported an average emission of 32 Kg CH_4 ha^{-1} yr^{-1} from a rainfed tropical rice ecosystem.

The tentative global estimate of N_2O emission from agricultural land is 2.3-3.7 Tg N yr^{-1} (Bouwman, 1990). Chao et al. (2000) estimated around 0.67 Mg N_2O-N yr^{-1} from the paddy fields of Taiwan. N_2O emission from the Chinese rice fields ranged from 39-164 mg N m^{-2} hr^{-1} (Chen et al., 1997). Agriculture related activities account for around 90% of the total N_2O emissions in India (Garg et al., 2001). Parashar et al. (1998) estimated the total N_2O emission from Indian paddy and wheat fields were 199-279 Gg per annum. Sharma et al. (1995) estimated N_2O emissions from irrigated and upland paddy fields of India at 4-210 and 2-10 Gg yr^{-1}, respectively. Nitrous oxide emission from Indian agricultural field was estimated to be 0.08 Tg annually (Bhatia et al., 2004). The irrigated rice-wheat system is a significant source of N_2O, emitting around 15 kg N_2O-N ha^{-1} yr^{-1} (Aulakh et al., 2001).

The Denitrification and Decomposition (DNDC) model was applied for estimation of GHG emissions from rice fields in India using a compiled soil - climate - land use database. Continuous flooding of rice fields (42.25 million ha) resulted in annual net emissions of 1.07–1.10, 0.04–0.05 and 21.16–60.96 Tg of CH_4-C, N_2O-N and CO_2-C, respectively, with a cumulated GWP of 130.93–272.83 Tg CO_2 equivalent. Intermittent flooding of rice fields reduced annual net emissions to 0.12–0.13 Tg CH_4-C and 16.66–48.80 Tg CO_2-C while N_2O emission increased to 0.05–0.06 Tg N_2O-N. The GWP, however, reduced to 91.73–211.80 Tg CO_2 equivalent (Pathak et al., 2005).

Conclusions

Greenhouse gas fluxes in terms of gaseous carbon and nitrogen between rice fields and the atmosphere are controlled by several biological and physical processes. The trace gas flux dynamics during rice cultivation follows complex pathways and shows variability at different time scales starting from diurnal variation to seasonal, annual and interannual variations. As many of the factors controlling gas exchange between rice paddies and atmosphere are different from other ecosystems, field studies should be designed to measure net fluxes and to improve understanding of the factors including detailed mechanisms controlling the fluxes in different rice production systems. Therefore, quantification of net fluxes of gaseous-C, in forms of CO_2-C and CH_4-C, and gaseous-N in the form of N_2O-N exchanged between the rice fields and atmosphere is required for quantification of those GHGs and to determine their impact on vegetation and on environment. The continuous monitoring and measurement would provide a useful understanding for examining the roles of different parts of rice and rice-based cropping systems contributing to GHG fluxes under different agro-climatic zones and management practices. This could be further calibrated, up scaled and validated by ecosystem modelling approach. The study can also be employed to explore better understanding of GHG exchanges with the help of remote sensing software applications for scaling up gaseous-C and N fluxes from point scale and it can further be extrapolated to upscale for predicting future anticipated climate changes. Therefore, research approaches are needed for enhancing knowledge and better understanding on the processes involved in gaseous carbon and nitrogen emissions in different agro-environments. The eddy covariance technique measures directly the net ecosystem CO_2 exchange for characterization of carbon budget in terrestrial ecosystems. This device when coupled with other accessory sensors and trace gas analyzers can measure also CH_4 as well as N_2O fluxes from rice fields. The trace gas flux dynamics during rice cultivation follows complex pathways and shows variability at different time scales starting from diurnal variation to seasonal, annual and interannual variations. Thus EC method along with IRGA-based soil and plant (canopy) respiration chamber and manual/ automatic chamber measurement of CH_4 and N_2O, can employ new methodologies that account for all components of GHG fluxes required for accurate quantification of trace gas exchange at the landscape level with regard to rice production. Moreover, this integrated measurement approach would provide a useful tool for examining the roles of different parts of rice ecosystem contributing to GHG fluxes in different rice production systems under different agro-climatic zones and management practices. The flux data of GHGs along with other climate parameters can be interpreted in a better way and tested via models that incorporate all biogenic greenhouse gases. These high-resolution process-based models can be applied to upscale and validate GHG emissions from any point and can be extrapolated to higher scales for predicting future anticipated climate changes. Impact of GHGs on climatic conditions and the influence of such climatic change on rice productivity is now reality, although there is a need to assess the extent of such influences.

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