Measurement of Greenhouse Gas Emission from Crop, Livestock and Aquaculture

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Foreword

Agricultural activities such as land clearing, cultivation of annual crops, irrigation, animal husbandry, fisheries and aquaculture have a significant impact on greenhouse gases (GHGs) emission and climate change. All the above changes will put tremendous pressure on agriculture resulting in considerable changes in emission of GHGs. Understanding trends in GHGs, their drivers, and the connection between the two is essential for understanding the need for mitigation and adaptation. Carbon dioxide is the most important anthropogenic GHGs followed by methane and nitrous oxide. The international community under the auspices of the United Nation Framework Convention on Climate Change (UNFCCC) is engaged in developing the policy to reduce GHGs emission and minimize the risks of climate change.

Several attempts have been made to measure the emissions of GHGs from agriculture including crop husbandry, animal husbandry and aquaculture. However, there are uncertainties in the measurements mainly because of the differences in the methodologies followed for such measurements. A standard methodology, therefore, should be followed to get uniformity and robustness in the data.

The Manual on Measurement of Greenhouse Gas Emission from Crop, Livestock and Aquaculture describes the methodologies for measurements of GHGs emission from various sub-sectors of agriculture in a simple and lucid way so that a researcher can adopt those methodologies easily.

I appreciate the efforts made by the authors and the editors in bringing out this Manual. I am sure this Manual will be useful for students and researchers engaged in GHGs emission and mitigation studies in agriculture.

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Chapter 1

Greenhouse Gas Emissions from Agriculture – An Introduction

H Pathak

Global warming, caused by the increase in the concentration of greenhouse gases (GHGs) in the atmosphere, has emerged as the most prominent global environmental issue. These GHGs i.e., carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) trap the outgoing infrared radiation from the earth's surface and thus raise the temperature. The global mean annual temperatures at the end of the 20th century, as a result of GHG accumulation in the atmosphere, has increased by 0.4–0.76 ^{o}C above that recorded at the end of the 19th century (IPCC 2007). The last 50 years show an increasing trend of 0.13 °C/decade whereas the trend of the last one and half decades has been much higher. The Inter-Governmental Panel on Climate Change (IPCC 2007) projected a temperature increase between 1.1 and 6.4 °C by the end of the 21st Century. Global warming also leads to other regional and global changes in climate-related parameters such as rainfall, soil moisture and sea level.

Global climatic changes can affect agriculture through their direct and indirect effects on the crops, soils, livestock and pests. An increase in atmospheric carbon dioxide level will have a fertilization effect on crops with C_3 photosynthetic pathway and thus will promote their growth and productivity. The increase in temperature, depending upon the current ambient temperature, can reduce crop duration, increase crop respiration rates, alter photosynthate partitioning to economic products, affect the survival and distribution of pest populations, hasten nutrient mineralization in soils, decrease fertilizer-use efficiencies, and increase evapo-transpiration rate. Indirectly, there may be considerable effects on land use due to snow melt, availability of irrigation water, frequency and intensity of inter- and intra-seasonal droughts and floods, soil organic matter transformations, soil erosion, changes in pest profiles, decline in arable areas due to submergence of coastal lands, and availability of energy. Therefore, concerted efforts are required for mitigation and adaptation to reduce the vulnerability of

Indian agriculture to the adverse impacts of climate change and making it more resilient.

Emission of GHGs from Indian agriculture

Carbon Dioxide

The main sources of carbon dioxide emission are decay of organic matter, forest fires, eruption of volcanoes, burning of fossil fuels, deforestation and land-use changes. Agriculture is also a contributor to CO_2 emission but is not considered as a major source of this important GHG. Within agriculture, soil is the main contributor with factors such as soil texture, temperature, moisture, pH, available C and N, influencing CO_2 emission from soil. Emission of CO_2 is more from a tilled soil than from an undisturbed soil (no till). Temperature has a marked effect on CO_2 emission from soil by influencing the root and soil respiration and also on CH_4 by effecting anaerobic carbon mineralization and methanogenic activity. It may be mentioned that plants, oceans and atmospheric reactions are the major sinks of carbon dioxide.

Table 1. Abundance and lifetime of greenhouse gases in the atmosphere

Parameters	CO_2	CH_4	N_2O	Chlorofluorocarbons
Average concentration 100 years ago (ppbV)	290,000	900	270	0
Current concentration (ppbV) (2007)	380,000	1,774	319	3-5
Projected concentration in the year 2030 (ppbV)	400,000-500,000	2,800-3,000	400-500	3-6
Atmospheric lifetime (year)	5-200	9-15	114	75
Global warming potential (100 years relative to CO_2)	1	21	310	4750-10900

Source: IPCC (2007)

Methane

Methane is about 21 times more effective as a heat-trapping gas than CO_2 (Table 1). The main sources of methane are: wetlands, organic decay, termites, natural gas and oil extraction, biomass burning, rice cultivation, cattle and refuse landfills. The primary sources of methane from agriculture include animal digestive processes, rice cultivation and manure storage and handling. The removal in the Stratosphere and soil are the main sinks of methane.

In ruminant animals, methane is produced as a by-product of the digestion of feed in the rumen under anaerobic condition. Methane emission is related to the composition of animal diet (grass, legume, grain and concentrates) and the proportion of different feeds (e.g. soluble residue, hemicellulose and cellulose content). Mitigation of methane emitted from livestock is approached most effectively by strategies that reduce feed input per unit of product output. Nutritional, genetic and management strategies to improve feed efficiency increase the rate of product (milk, meat) output per animal. Because most CH_4 is produced in the rumen by fermentation, practices that speed the passage of feed from the rumen can also reduce methane formation.

Methane is also formed in soil through the metabolic activities of a small but highly specific bacterial group called 'methanogens'. Their activity increases in the submerged, anaerobic conditions developed in the wetland rice fields, which limit the transport of oxygen into the soil, and the microbial activities render the water-saturated soil practically devoid of oxygen. The upland, aerobic soil does not produce methane. Water management, therefore, plays a major role in methane emission from soil. Altering water management practices, particularly mid-season aeration by short-term drainage as well as alternate wetting and drying can greatly reduce methane emission from rice cultivation. Improving organic matter management by promoting aerobic degradation through composting or incorporating into soil during off-season drain-period is another promising technique.

Nitrous oxide

As a greenhouse gas, nitrous oxide is 310-times more effective than CO_2. Forests, grasslands, oceans, soils, nitrogenous fertilizers, and burning of biomass and fossil fuels are the major sources of nitrous oxide, while it is removed by oxidation in the Stratosphere. Soil contributes to the largest amount of nitrous oxide emission. The major sources are soil cultivation, fertilizer and manure application, and burning of organic material and fossil fuels. From the agricultural perspective, nitrous oxide emission from soil represents a loss of soil nitrogen, reducing the nitrogen-use efficiency. Appropriate crop-management practices, which lead to increased N-use efficiency, hold the key to reduce nitrous oxide emission. Site-specific nutrient management, fertilizer placement and proper type of fertilizer supply nutrients in a better accordance with plant demands, thereby reducing nitrous oxide emission.

Mitigation strategies to greenhouse gas emission

The strategies for mitigating methane emission from rice cultivation could be alteration in water management, particularly promoting mid-season aeration by short-term drainage; improving organic matter management by promoting aerobic degradation through composting or incorporating it into soil during off-season drained period; use of rice cultivars with few unproductive tillers, high root oxidative activity and high harvest index; and application of fermented manures like biogas slurry in the place of unfermented farmyard manure (Pathak and Wassmann 2007). Methane emission from ruminants can be reduced by altering the feed composition, either to reduce the percentage which is converted into methane or to improve the milk and meat yield. Secondary plant metabolites and plant extracts have also been found to reduce methane emission from livestock, therefore are likely to be used in future for methane mitigation in livestock production system.

The most efficient management practice to reduce nitrous oxide emission is site-specific, efficient nutrient management (Pathak 2010). The emission could also be reduced by nitrification inhibitors such as nitrapyrin and dicyandiamide (DCD). There are some plant-derived organics such as neem oil, neem cake and karanja seed extract which can also act as nitrification inhibitors.

Mitigation of CO_2 emission from agriculture can be achieved by increasing carbon sequestration in soil through manipulation of soil moisture and temperature, setting aside surplus agricultural land, and restoration of soil carbon on degraded lands. Soil management practices such as reduced tillage, manuring, residue incorporation, improving soil biodiversity, micro aggregation, and mulching can play important role in sequestering carbon in soil. Some technologies such as intermittent drying, site-specific N management, etc. can be easily adopted by the farmers without additional investment, whereas other technologies need economic incentives and policy support (Wassmann and Pathak 2007).

Conclusions

For India's agricultural production systems to be viable into the future there is a need to identify soil management systems that are climate change compatible, where soil organic C is maintained or enhanced and GHGs emission is reduced. It would require increased mitigation and adaptation research, capacity building, development activities and changes in land-use management. A win-win solution is to start with such mitigation strategies that are needed for sustainable development such as increasing soil organic carbon content. Policies and incentives should be

evolved that would encourage farmers to adopt mitigation options thus improve soil health and use water and energy more efficiently.

References

IPCC (2007) The Physical Science Basis. In: Solomon, S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (Eds.) Climate Change 2007: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Pathak H, Wassmann R (2007) Introducing greenhouse gas mitigation as a development objective in rice-based agriculture: I. Generation of Technical Coefficients. Agric Syst 94: 807-825.

Wassmann R, Pathak H (2007) Introducing greenhouse gas mitigation as a development objective in rice-based agriculture: II. Cost–benefit assessment for different technologies, regions and scales. Agric Syst 94: 826-840.

Pathak H (2010) Mitigating greenhouse gas and nitrogen loss with improved fertilizer management in rice: Quantification and economic assessment. Nutr Cycling Agroecosys 87: 443-454.

Greenhouse Gas Emissions from Crops

Chapter 2

Measurement of Greenhouse Gas Emissions from Crop Fields

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Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are important greenhouse gases (GHGs) contributing 60, 15 and 5%, respectively, towards the enhanced global warming (IPCC 2007). The methodologies for measurement of emission of these GHGs from soil-plant systems are described below.

Methane and nitrous oxide

Two methods: Closed-chamber method and micrometeorological method are generally used to measure methane and nitrous oxide emissions from soils. This chapter deals with the most widely used closed-chamber method for gas sampling.

Closed-chamber technique

Gas flux from the soil using closed-chambers can be determined by collecting gas samples periodically from the chambers and measuring the change in concentration of a gas with time during the period of linear concentration change (Hutchison and Mosier 1981). Chambers can be made from materials like rigid plastic, perspex or acrylic sheets. For collecting gas samples from crop fields, generally, chambers of 50 cm × 30 cm × 100 cm (Fig. 1 and 2) made of 6-mm acrylic sheets are used. Head space volume and temperature inside the chamber is recorded, which is used to calculate flux of gas. Gas samples should be taken from the headspace immediately after sealing and at equal time intervals thereafter over a period not exceeding 2 hours. To check the linearity of gas concentration increase in the chamber at least three measurements should be taken. A departure from linearity indicates either an inadequately sealed chamber or the decrease in gas concentration gradient between the zone of production in the soil and the chamber atmosphere changes

the gas diffusion rate with time. The gas samples should be analyzed immediately in the gas chromatograph (GC) to prevent the diffusion loses. The chamber cover should be removed immediately after collecting the final sample to minimize the disturbance to environmental conditions within the enclosure formed by the chamber wall.

To transfer gas samples over long distances to the analytical laboratory, evacuated vials fitted with rubber/silicon septa (e.g. vacutainers/exetainers) can be used satisfactorily. The septa on the vials should be cleaned with a detergent and the vials evacuated by a vacuum pump before use. An alternative method is the use of glass serum bottles fitted with butyl rubber stoppers. The vials are taken to the sampling site, and filled with the gas sample with a syringe. By injecting sufficient sample to achieve an over-pressure, e.g. 10 mL into a 9-mL vial, contamination
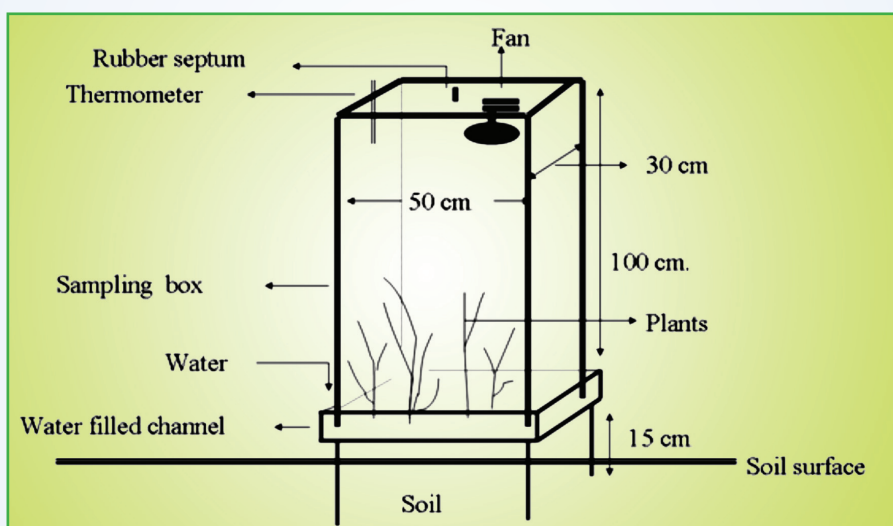
Fig. 1. Closed-chamber used for collection of greenhouse gas samples from field

Fig. 2. Collection of GHGs samples from field using the closed-chamber method

problems are prevented. The methodology of gas sample collection and analysis of different gases has been illustrated step-wise as follows.

Collection of gas samples

For collection of gas samples acrylic/perspex chambers of 50 cm × 30 cm × 100 cm size (according to experiment i.e., type and stage of the crop growth, etc.) is placed on the aluminum channel inserted 10 cm inside the soil and the channels filled with water to make the system air-tight. One silicon septum is fitted at the top of chamber to collect gas samples. The air inside the chamber should be homogenized with the battery operated fan or air circulation pump with an air displacement of 1.5 L min^{-1} during collection of gas samples from the field for proper mixing (homogenization) of gases inside the chamber. Gas samples can be drawn with 20-50 mL syringe with the help of 24 gauge hypodermic needle at an interval of at 0, 1/4, 1/2 and 1 hrs. After drawing sample, the syringe should be made air tight with three way stop cock. Air temperature and head space volume inside the box required for calculation of GHGs flux should be recorded.

Analysis of gas samples

Methane

Concentration of methane in the gas samples is analyzed by Gas Chromatograph (GC) fitted with a flame ionization detector (FID). The FID is used for detection of substances, which produce ions when heated in an H_2-air flame. The detector is unable to detect permanent gases, water and inorganic ions, which do not ionize at 2100 °C. The sample enters the hydrogen jet via millipore filter with the eluent (carrier gas). The sample components get ionized to form ions and free electrons on entering the flame at the tip of the jet. The electrons produced are drawn towards the collector. Hence there is a flow of current. The current flow across an external resistor, sensed as a voltage drop, is amplified and displayed on the recorder. The entire assembly is housed in an oven to prevent condensation of water vapour formed as a result of combustion.

Gas samples containing methane are introduced into the gas chromatograph by a syringe fitted with a three-way nylon stopcock through a gas sampling valve in the injection port. A gas sample loop of 1 or 2 cm^3 is fitted to the sample valve to inject same volume of gas from each sample. Methane analysis can be accomplished by various modifications of GC settings and column materials. The various parameters of GC have to be optimized empirically in order to achieve a satisfactory separation and detection. Methane can be separated from other gaseous

components on a Porapak N or Porapak Q column (3-m-long stainless steel or nickel with 3.175-mm outside diameter) with column temperature maintained at 70 °C and carrier gas flow (helium, nitrogen or argon) of 20-30 cm^3 min^{-1}. Methane is detected using a FID maintained at 250 °C. H_2 with a flow rate of 30-40 ml min^{-1} is used for FID. The sampling valve can be accentuated manually, pneumatically or electronically using computer software or GC- microprocessor. A GC-software is used to plot and measure the peak area. The CH_4 standards (1, 5 and 10 ppm) are used as a primary standard.

Nitrous oxide

Concentration of nitrous oxide in the gas samples is analysed by Gas Chromatograph fitted with an electron capture detector (ECD) and 6' x 1/8" stainless steel column (Porapak N). The ECD is used for the detection of electrophilic substances. The detector consists of two electrodes, one of which is treated with radioactive ^{63}Ni (or titanium or scandium), which emits beta rays. These high-energy electrons bombard the carrier gas (N_2 or argon mixture) to produce large numbers of low energy (or thermal) secondary electrons. These electrons are collected by the other positively polarized electrode. This steady state current is reduced when an electrophilic sample component passing through the space between the two electrodes captures some of these electrons and provides an electrical reproduction of the GC peak. The temperatures of column and detector are kept at 50 °C, and 300 °C, respectively. The flow rates of carrier back flush and detector purge gases (95% argon + 5% methane or N_2) are kept as 14-18 cm^3 min^{-1}. Gas samples are introduced into a gas sampling loop (size depends upon the sensitivity of the ECD used) through a gas injection port. Both CO_2 and water vapours are removed from the gas samples. The two absorbent traps are prepared by packing 10-mm millipore syringe filter holders with Ascarite and $MgClO_4$. A GC-software is used to plot and measure the peak area. The N_2O standard (300, 500 and 1000 ppbV) is used as primary standards.

Calculation of flux

The flux of methane and nitrous oxide is calculated using the following equations.

Cross-sectional area of the chamber (m^2)   =   A

Headspace (m)   =   H

Volume of headspace (L)   =   1000 X AH

CH_4 concentration at 0 time ($\mu L\ L^{-1}$)   = C_o

CH$_4$ concentration after time t (μL L^{-1})   =   C$_t$

Change in concentration in time t (μL L^{-1})   =   (C$_t$ -C$_o$)

Volume of CH$_4$ evolved in time t (μL)   =   (C$_t$ -C$_o$) X 1000 AH

When t is in hours, then flux (mL m^{-2} h^{-1})   =   [(C$_t$-C$_o$) X AH)/(A X t)

Now 22.4 mL of CH$_4$ is 16 mg at STP

Hence, CH$_4$ flux =   [(C$_t$ - C$_o$)/t] X H X 16/22.4 X 10000 X 24 mg ha^{-1} d^{-1}

        N$_2$O flux =   [(C$_t$ - C$_o$)/t] X H X 44/22.4 X 10000 X 24 mg ha^{-1} d^{-1}

Precautions

While using the closed-chamber technique for GHG flux measurement, following precautions should be taken.

- While collecting the gas samples from rice crop the chamber should be placed on the soil in such a way that 4-6 plants are inside the chamber.

- In upland irrigated/rainfed crops the chamber should be placed in between the rows/plants to collect the samples.

- The height of the chamber should be more than 30 cm.

- The chamber headspace N$_2$O concentration at zero hour should be measured accurately. For this the first air sample inside the chamber should be taken immediately after the chamber placement on the channel/collar in case of cylindrical chambers.

- Air samples should be taken in as short a time as possible to observe a measureable increase in headspace gas concentration. Longer chamber deployment durations may result in negative impacts.

- To reduce the uncertainty arising out of spatial variability more number of chambers should be deployed. The uncertainty due temporal variability can be reduced by increasing the sampling frequency. Longer period of sampling results in better precision however too long period may yield sampling artifacts.

- To avoid the diurnal variation the gas samples from the field should be collected in definite time span in day throughout the cropping season, preferably during 0900-1100 and 1500-1700 hours.

Carbon dioxide

For quantitative analysis of CO$_2$ emission from soil generally three methods are used: Closed-chamber method, Soil respirator method and Infra-red gas analyzer

method. Alkali trap method is also used and is discussed in Chapter 6 in this manual.

1. Closed-chamber method

The CO_2 flux from the soil using closed-chambers can be measured by collecting gas samples at periodic interval and measuring the change in concentration with time during the period of linear concentration change similar to sampling of methane and nitrous oxide. The analysis can be done in gas chromatograph fitted with FID (discussed above) and a methanizer. The methanizer consists of a 6″ x 1/8″ stainless steel tube which is mounted alongside the edge of the heated valve oven, and thermostated to 380 °C. The tube is packed with an activated nickel/zinc/Pt-Pd catalyst powder. Column effluent is mixed with hydrogen gas at a rate of 20 ml/min before entering the methanizer. The methanizer converts the, CO and CO_2 to methane and can be detected by the FID. Hydrocarbons such as methane, ethane and propane pass through the methanizer unaffected. The response of CH_4 produced from CO_2 on the FID is much greater compared to methane in the sample. Methanizer tubes can be poisoned by large amounts of sulfur gas. Calculation of flux can be done similar to methane as CO_2 is measured as methane (discussed above).

The CO_2 concentration in samples can also be analyzed using gas chromatograph equipped with thermal conductivity detector (TCD) and 3 m long and 0.3 cm internal diameter HayeSep D column. Helium is used as a carrier gas at a flow rate of 25 cm^3 min^{-1}. Oven and detector temperatures are 50 and 150 °C, respectively. Standard CO_2 samples (350, 500 and 700 ppm) are to be used for GC calibration.

Flux of gases (F as g CO_2-C m^{-2} day^{-1}) can be computed as:

$$F = (\Delta g/\Delta t) (V/A) k$$

Where $\Delta g/\Delta t$ is the linear change in CO_2 concentration inside the chamber (g CO_2-C m^{-3} min^{-1}); V is the chamber volume (m^3); A is the surface area of the chamber (m^2) and k is the time conversion factor (1440 min day^{-1}). Chamber gas concentration can be converted from molar mixing ratio (ppm) determined by GC analysis to mass per volume by assuming ideal gas relations. Hourly CO_2 fluxes are calculated from the time vs. concentration data using the following formula.

$$CO_2\text{-C flux} = (\Delta X \times EBV_{(STP)} \times 12 \times 10^3 \times 60) / (10^6 \times 22400 \times T \times A)$$

Where, ΔX = Difference in flux value between 30 min and 0 min (converted to ppm based on the standard CO_2 values), EBV= effective box volume, T= Flux time in min, A= cross sectional area of the chamber.

2. Infra-red analyzer method

Carbon dioxide can be analyzed using Infra-red-based continuous soil CO_2 flux analyzer. The analyzer can be used with a 20 cm short term survey chamber to obtain soil CO_2 flux (Figure 3). The survey chamber is placed on the soil and the rate of change of the CO_2 concentration inside the chamber is used to determine the soil flux. As the chamber CO_2 concentration increases, the concentration gradient between the soil and the chamber air decreases. This results in exponential decrease in the measured soil CO_2 flux with time. The desired value of the soil flux can be determined when the chamber CO_2 concentration is the same as the ambient atmospheric concentration. The flux can be estimated using the initial slope of a fitted exponential curve at the ambient CO_2 concentration. This is done to minimize the impact of the altered CO_2 concentration gradient across the soil surface after chamber was closed.

Infra-red gas analyzer (IRGA)-based field measurement technique is used for quantifying CO_2 emission rates in enclosed-chamber over a specified time. The CO_2 emission is measured with an environmental gas monitor chamber (closed dynamic chamber) attached to a data logger A flag is placed as a marker in the plot where CO_2 emission is measured. The chamber is 15 cm tall, 10 cm in diameter and has capacity to measure CO_2 emission from 0-9.99 g CO_2-C m^{-2} h^{-1}. The chamber is placed at the soil surface for 2 minute for each plot until CO_2 emission measurement is recorded in the data logger. All measurements are taken between 0900 to 1100 hours in the morning and between 1500 to 1700 hours in the afternoon in close intervals (3-4 days) throughout the year. The average between the morning and

Fig. 3. Collection of CO_2 samples from field using the Infra-red analyzer and soil respiration chamber method

evening emissions is considered as the daily mean emission (Bhattacharyya et al. 2012, Bhattacharyya et al. 2013).

Infra-red gas analyzer (IRGA)-based field measurement is the most widely used technique for assessing soil respiration rates (Fig. 3). The method estimates the increase in enclosed chamber CO_2 concentration over a specified time. 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.

3. Soil respirator method

The soil respiration i.e., flux of CO_2 per unit area per unit time, is measured by placing a closed-chamber on the soil and measuring the rate of increase in the CO_2 concentration inside the chamber. The soil respiration system consists of a soil respiration chamber (SRC) and an environmental gas monitor (EGM). For soil respiration, a chamber of known volume is placed on the soil and the rate of increase in CO_2 concentration within the chamber is monitored. With this system, the air is continuously sampled in a closed circuit through the EGM and the soil respiration rate is calculated, displayed and recorded by the analyzer. The air within the chamber is carefully mixed to ensure representative sampling without generating pressure differences, which would affect the evolution of CO_2 from the soil surface.

It is assumed that the rate of increase in CO_2 concentration is linear, though any leakage will cause a decline in its concentration with time. A quadratic equation is fitted to the relationship between the increasing CO_2 concentration and elapsed time. The flux of CO_2 per unit area and per unit time is measured using:

$$R = \frac{(C_n - C_o)}{T_n} \times \frac{V}{A}$$

Where, R is the soil respiration rate (flux of CO_2 per unit area per unit time), Co is the CO_2 concentration at zero time i.e. T=0 and Cn is the concentration at the time Tn, A is the area of soil exposed, and V is the total volume of the chamber.

References

Hutchinson GL and Mosier AR (1981) Improved soil cover method for field measurement of nitrous oxide flux. Soil Sci Soc Am J 45: 311-316.

IPCC (Intergovernmental Panel on Climate Change) (2007) Climate Change, The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Summary for Policymakers, Cambridge University Press, Cambridge UK.

Bhattacharyya P, Roy KS, Neogi S, Adhya TK, Rao KS and Manna MC (2012) Effects of rice straw and nitrogen fertilization on greenhouse gas emissions and carbon storage in tropical flooded soil planted with rice. Soil Tillage Res 124:119-130.

Bhattacharyya P, Nayak AK, Mohanty S, Tripathi R, Mohammad Shahid, Anjani Kumar, Raja R, Panda BB, Roy KS, Neogi S, Dash PK, Shukla AK and Rao KS (2013) Greenhouse gas emission in relation to labile soil C, N pools and functional microbial diversity as influenced by 39 years long-term fertilizer management in tropical rice. Soil Tillage Res 129:93-105.

Chapter 3

Measurement of Integrated Greenhouse Gas Flux with Eddy Covariance Technique

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Eddy covariance (EC) is a micrometeorological technique to measure vertical turbulent flux of water, carbon dioxide, heat, methane, ozone and volatile organic components in the atmospheric boundary layer. The eddy covariance (also known eddy flux) technique provides a direct measure of the turbulent flux of a scalar across horizontal wind streamlines (Paw et al. 2000). It is a statistical method used in meteorology and other applications that analyzes high-frequency wind and scalar atmospheric data series, and yields values of fluxes of these properties.

Purpose and application of Eddy covariance system

The EC technique is best applied for over flat terrain, when the environmental conditions are steady, and the underlying vegetation extends upwind for an extended distance. EC flux measurements are often used to estimate the integrated emission on a hectare scale with a continuous coverage in time (Hendriks et al. 2008). The technique is also used extensively for verification and tuning of global climate models, meso-scale and weather models, complex biogeochemical and ecological models, and remote sensing estimates from satellites and aircraft. The EC is potentially of great use to many non-meteorological sciences, industrial monitoring, carbon storage and sequestration, landfill and environmental management, and monitoring of actual emission rates of energy, water or gas exchanges and balances. Data from flux sites help in testing physiological models of C exchange and are critical to relating fluxes and remote sensing data. Combined physiological and ecological measurements enable partitioning of carbon fluxes into plant and soil components and reveal mechanisms responsible for these fluxes. At some sites, biomass-based estimates of C storage have validated C budgets from direct flux data and vice-versa. Data from the flux sites have been applied in ecology, weather forecasting, and climate studies, especially for sites with several

years of data to quantify inter-annual flux variations. The important applications of eddy covariance flux tower in agricultural studies are following:

- Gross Primary Production (GPP)
- Ecosystem Respiration (RE)
- Net Primary Production (NPP)
- Trace Gas Emissions
- Hydrologic and Energy Partitioning
- Net Ecosystem Production (NEP)
- Biogeochemistry
- Greenhouse Gases measurement

Evidence of anthropogenic climate change is now undeniable. Predictions and preparedness for future course lie in estimating future emissions and the dynamics of terrestrial sinks. Eddy covariance flux tower is the best techniques for measuring the flux of greenhouse gases from the agricultural fields. To understand the processes and mechanisms of agricultural ecosystem, carbon and water cycle and energy balance eddy covariance is a promising technique.

Greenhouse gases measurement

The methods that are generally employed to measure GHGs emissions from soil are closed-chamber method, open-chamber method, and micrometeorological method or the eddy covariance technique. Eddy covariance is the preferable technique for flux measurements since it is the only direct flux determination method (Fig. 1).
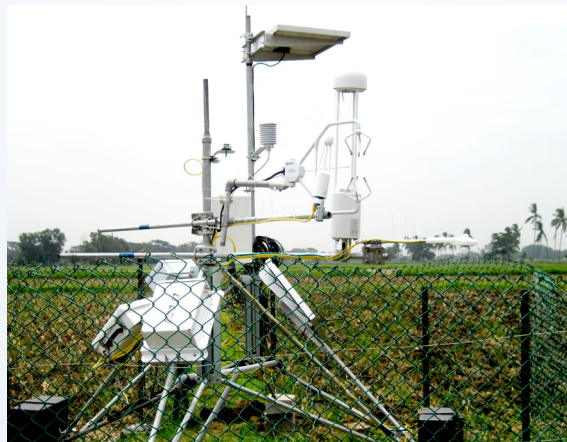

Fig. 1. Eddy covariance flux tower for greenhouse gas emission measurement

Advantages of the Eddy covariance system

The EC method can be used for a continuous in-situ, measurements over the large area with non-invasive sampling causing no disturbance to the area over which fluxes are measured. The values of gas exchange or emission rates are highly reliable, defensible and can be verified. The system has very short response time. It also provides information on short-term variation of fluxes with fast sampling and high precision. The automated measurement system provides continuous coverage with little intervention.

Principle of eddy covariance flux measurement system

The EC technique is based on high frequency (10-20 Hz) measurements of wind speed and wind direction as well as CO_2 and H_2O concentrations at a point over the canopy using a three-axis sonic anemometer and a fast response infrared gas analyzer. The two sensors, three-axis sonic anemometer and fast response infrared gas analyzer, are normally installed at 2-3 m height (depends on the crop canopy height) on a tripod mast or in case of forests on top of 30-40 meters tall towers with a sensor separation of 15-20 cm. The data obtained from three-axis sonic anemometer and CO_2 / H_2O infrared gas analyzer, is sampled at 10 and or 20 Hz using a fast-response data logger. The mean vertical flux density of CO_2 is obtained as the 30 minute covariance between vertical fluctuations (ω') and the CO_2 mixing ratio (c') (Baldocchi 2003):

$$F_z = \rho a \ . \ \overline{\omega' \ c'} \qquad (1)$$

In the equation (1) ρa refers to the air density, the overbars denote time averaging, and primes represent fluctuations about average value. A positive covariance between ω' and c' indicates net CO_2 transfer into atmosphere and a negative value indicates net CO_2 absorption by the vegetation. Net ecosystem exchange (NEE) is calculated as the sum of CO_2 storage change (F_s) within the air space below flux measuring height and the eddy CO_2 flux (F_c).

EC flux data are usually subject to varying degrees of quality checks because of the reason that data may be affected by precipitation, improper functioning or problem in the instrument, and or inappropriate meteorological conditions for flux studies. For proper EC flux measurement studies integral turbulent characteristics test and stationarity test of the half-hourly flux data are conducted. The percentages of the datasets which pass these two tests are then processed for further calculation and other data are rejected.

The EC system is setup in the centre of flat, homogeneous vegetation / crop field having enough fetch for micrometeorological flux measurement depending upon the prevalent wind direction. The partitioning of NEE into GPP and RE is done using conventional mathematical modeling approach wherein GPP and RE are expressed as empirical functions of meteorological variables. GPP is the CO_2 uptake by the photosynthesis of vegetation and RE represents CO_2 release through respiration of soil, roots, stems and leaves of plants. Night time RE (RE (N)) is determined using EC system from night time NEE, as at night time NEE is equal to night time ecosystem respiration (RE (N)), since GPP=0. NEE in night time hours is expressed as an exponential function of air temperature (T) and the function is then applied to the daytime for estimating RE in day time (RE (D)) (Falge et al. 2001; Greco and Baldocchi 1996).

$$RE\ (N) = R_0\ Q_{10}^{[(T-T_0)\ /\ 10]} \qquad (2)$$

Where, R_0 and Q_{10} are empirical constants determined by running regression analysis between RE (N) and temperature $(T-T_0)\ /\ 10$; T can either be air or soil temperature and T_0 is the reference temperature. Based on the assumption that the daytime temperature response of RE is the same as that of the night time RE, the above mentioned Eq. (2) is applied to the daytime data to estimate daytime half-hourly RE (RE (D)) and the GPP (F_{GPP}) is calculated as:

$$F_{GPP} = -F_{NEE} + RE\ (D) \qquad (3)$$

Where, F_{NEE} denotes NEE (Davis et al. 2003; Falge et al. 2002). The GPP is generally expressed as a rectangular hyperbolic function of incident photosynthetically active radiation (Q_P),

$$F_{GPP} = P_{max}\alpha Q_P/(P_{max}+\alpha Q_P) \qquad (4)$$

Where, P_{max} and α are empirical constants to be determined by regression between GPP and PAR (Gu et al., 2002). P_{max} means the hypothetical maximum of GPP or the closeness to the linear response coefficient, and α denotes the initial slope of the function or ecosystem quantum yield. There is a need to gap-fill those missing values of eddy flux data which are rejected by quality control tests or due to instrument malfunctioning. For CO_2 flux non-linear regression analysis are performed for gap-filling missing data of few hours or more and missing values are estimated from meteorological variables. For gap-filling of night time NEE data, Eq. (2) is used. To gap-fill daytime NEE data, RE (D) and GPP are first gap-filled. RE (D) is gap-filled using Eq. (3) and GPP is gap-filled using Eq. (4) (Bhattacharyya et al. 2013 a, b).

Components of Eddy covariance system

1. Fast-response greenhouse gas Sensors (CO_2, H_2O, CH_4, etc.)

2. Air Temperature and RH Sensor

3. Fast-response three-axes wind Speed and Direction Sensors

4. 4-component net Radiation Sensors

5. Surface Temperature Sensor

6. Canopy Temperature Sensor

7. Soil Heat Flux Plates

8. TDR Probe Used

9. Surface/ Soil Thermocouple Array

10. Barometric Pressure

11. Fast-response data-loggers

12. Data Acquisition, Transmission/ Storage

13. Multiplexers Power Source

14. Tower

15. Photosynthetic photon flux density (PPFD) sensor

Eddy covariance system

A typical eddy covariance system includes a CO_2/H_2O gas analyzer, 3-dimensional sonic anemometer, data logger, and uninterrupted power supply (Fig. 2). With the recent development of a low power, high precision CH_4 analyzer, methane
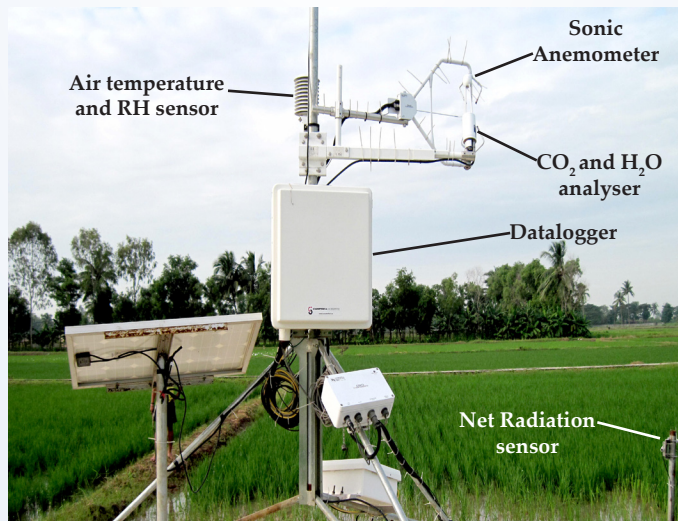

Fig. 2. Various components of the Eddy covariance flux tower

measurements into conventional eddy covariance stations can be integrated. In addition to high speed (>10 Hz), high precision instruments required by the eddy covariance system, it is also important that the system is flexible and allows easy integration of additional sensors when required.

The eddy covariance method relies on the combined measurements of gas, temperature and wind speed data to compute flux rates. When selecting instrumentation for eddy covariance research, one critical decision is whether to use an open path or closed path analyzer. Open and closed path instruments each possess certain advantages and disadvantages. For example, open path analyzers have lower power requirements than closed path analyzers, but closed path analyzers are less sensitive to the interruptions caused by the environment.

CO_2/H_2O analyzer

Water vapor and carbon dioxide are the two most important greenhouse gases affecting global climate change. Fluxes of both of these gases can be measured directly, in a verifiable and defensible manner, using the eddy covariance method. Carbon dioxide flux measurements are required to assess carbon exchange and carbon emission rates, and to construct carbon budgets over natural, agricultural and urban ecosystems, as well as over industrial areas such as sequestration lands, landfills, feedlots, etc. These data could also be used to refine models of the global carbon cycle, to estimate carbon credits or footprints, or to verify compliance with regulations for carbon emissions.

Water vapor flux measurements are critical for a number of applications in precision agriculture such as water management, irrigation, and hydrological applications, agricultural and climate modeling and remote sensing verification. Water vapor is also important for computing eddy covariance fluxes of other atmospheric gases because it affects the measured densities of the gases, such as CO_2 and CH_4. Calibration of the analyzer is done every 6 months against a dew point generator for water vapor and a standard gas for CO_2. Span values of two consecutive calibrations usually differ by less than 3%.

CH_4 analyzer

Methane is recognized as the third most important greenhouse gas, after H_2O and CO_2. By the development of a low power open path CH_4 analyzer in 2010 it has now become possible to measure methane fluxes in regions without grid power supply. This solved the problem presented by old high power analyzers, which often require grid power to supply energy to vacuum pumps and temperature

control systems. The use of such devices is geographically restricted. Therefore in several remote regions methane dynamics are still not understood. Limited studies have been conducted in some important methane-producing areas such as permafrost regions, rice fields, animal facilities, and landfills. A low power, high speed, high precision, self-cleaning methane analyzer is a great addition to an eddy covariance tower. Widespread methane flux measurements are now possible and urgently needed in order to understand sources and sinks of atmospheric methane around the globe.

Three dimensional sonic anemometer

Vertical wind speed is a critical component of the eddy covariance method. When computing fluxes, the vertical wind speed indicates the direction and the transport rate of energy, carbon dioxide, or other gases into or out of the ecosystem. In addition, the sonic anemometer measures air temperature, an important variable for flux computation.

Data storage

Eddy covariance instruments generate large amounts of data. Data logger, an analyzer interface unit that outputs data over the Ethernet, and also a removable industrial-grade USB drive that can store long-term data are essential requirements.

Power supply

The electrical grid does not extend into most natural and agricultural environments. Instead, small photovoltaic solar power systems are often used to power eddy covariance systems. A well-designed photovoltaic power system can deliver continuous power to an eddy covariance system, even in the regions with less solar radiation.

Other sensors

Some eddy covariance systems may use additional sensors to provide supporting meteorological data. These sensors include:

- 4 component Net Radiometer – to measure total incoming and outgoing radiation, used to evaluate the energy balance

- Soil Heat Flux Plates (at 3-4 different soil depths)

- Soil Temperature Sensors (at 3-4 different soil depths)

- Soil Moisture Sensors (at 3-4 different soil depths)

- Air Temperature and Relative Humidity Sensors

- Precipitation Sensors

- Quantum Sensor – to measure photosynthetically active radiation (PAR)

- Data Logger – for studies that use many sensors, an additional data storage device may be required

Software and data collection

Eddy covariance instruments are configured through computer software. The software usually provides access to basic and advanced configuration options, as well as graphing of the live data stream. The software allows to

- Configure sampling rate

- Configure auxiliary sensor inputs

- Select variables to log

- Set up data logging options

Currently there are several software programs to process eddy covariance raw data and derive quantities such as heat, momentum, and gaseous fluxes. Examples include EdiRe, ECpack, TSA, TK2, Alteddy, EddySoft and EdiPro, Each software has its own benefits depending on the requirements of the user, e.g. online versus off-line calculation of fluxes, graphical outputs, control tools etc. However, the calculation and correction procedures should not differ between software packages that are published by the processing of the same time series raw data with identical conceptual assumptions.

Data files

Eddy covariance data sets are typically logged at 10 Hz (10 samples per second) in a regular ASCII text file format, which can be read in most spreadsheet applications.

Flux calculations and associated errors

Processing eddy covariance data is accomplished using any of multiple flux computation applications. Computing fluxes includes checking data for errors or gaps, aligning data to account for time delays, and computing fluxes based on

half-hour or one hour averaging intervals. Following are some major assumption requirements of the eddy covariance flux tower.

- Fluxes are measured only at area of interest
- Measurements are done inside the boundary layer of interest
- Terrain is horizontal and uniformed; average of fluctuations is zero; density fluctuations negligible; flow convergence & divergence negligible
- Measurements at a point can represent an upwind area
- Flux is fully turbulent and most of the net vertical transfer is done by eddies
- Instruments can detect very small changes at high frequency, ranging from minimum of 5 Hz and to 40 Hz for tower-based measurements

There are a number of potential flux errors due to assumption, instrument problems, physical phenomena and specifics of the terrain. The key errors in the measurement of flux are time response, sensor separation, scalar path averaging, tube attenuation, high pass filtering, low pass filtering, sensor response mismatch, digital sampling, sensor time delay, spike and noise, unleveled instrumentation, density fluctuation, sonic heat flux error, band-broadening, oxygen in 'krypton' path and data filling. To minimize such error a number of procedures could be performed which are given in the Table 1.

Table 1. Error reason, range and remedy of the affected flux of eddy covariance flux tower

Errors due to	Affected flux	Range	Remedy
Frequency response	All	5-30%	Frequency response correction
Time delay	All	5-15%	Adjusting for delay
Spike & noise	All	0-15%	Spike removal
Unleveled inst/flow	All	0-25%	Coordinate rotation
Density fluctuation	H_2O, CO_2, CH_4	0-50%	Webb Pearman Leuning Correction
Sonic heat error	Sensible heat	0-10%	Sonic temperature correction
Brand Broadening	Mostly CO_2, CH_4	0-5%	Brand Broadening correction
O_2 in path	Some H_2O	0-10%	O_2 correction
Missing data filling	All	0-20%	Methodology/Test

Limitations

- It requires a continuum of high time resolution measurements (e.g. 5–20 Hz).
- The technique is mathematically complex, and requires significant care in setting up and processing data.

- These Flux towers provide information specific to a single ecosystem type or condition.

- Flux data are noisy, and this uncertainty is largely due to random measurement error.

- There are a number of situations where the EC method either could not be used to measure fluxes, or is not the best method to do so. These include environmental conditions with a very small area of study, predominantly low winds, complex terrain, point flux sources etc. Also, for some gases, such as ammonia and volatile compounds, the instrument system may not be sensitive enough to measure small changes at 10 or 20 Hz frequencies.

- It requires a number of assumption and correction and demands careful design, execution and processing that is fit to the specific purpose at the specific experimental site.

- The study area should be flat, homogeneous and it should represent the similar ecology

References

Baldocchi DD (2003) Assessing the eddy covariance technique for evaluating carbon dioxide exchange rates of ecosystem: past, present and future. Global Change Biology 9: 479-492.

Bhattacharyya P, Neogi S, Roy KS, Dash PK, Tripathi R and Rao KS (2013b) Net ecosystem CO_2 exchange and carbon cycling in tropical lowland flooded rice ecosystem. Nutr Cycling Agroecosys 95:133-144.

Bhattacharyya P, Neogi S, Roy KS and Rao KS (2013a) Gross primary production, ecosystem respiration and net ecosystem exchange in Asian rice paddy: An eddy covariance based approach. Curr Sci 104: 67-75.

Davis KJ, Bakwin PS, Yi C, Berger BW, Zhaos C, Teclaw RM and Isebrands JG (2003) The annual cycles of CO_2 and H_2O exchange over a northern mixed forest as observed from a very tall tower. Global Change Biology 9: 1278-1293.

Falge E, Baldocchi D, Olson R, Anthoni P, Aubinet M, Bernhofer C, Burba G, Ceulemans R, Clement R, Dolman H, Granier A, Gross P, Grunwald T, Hollinger D, Jensen NO, Katul G, Keronen P, Kowalski A, Lai CT, Law BE, Meyers T, Moncrieff J, Moors E, Munger JW, Pilegaard K, Rannik U, Rebmann C, Suyker A, Tenhunen J, Tu K, Verma S, Vesala T, Wilson K and Wofsy S (2001) Gap filling strategies for defensible annual sums of net ecosystem exchange. Agricultural and Forest Meteorology 107: 43-69.

Falge E, Baldocchi DD, Tenhunen J, Aubinet M, Bakwin P, Berbigier P, Bernholer Ch, Burba GG, Clement R, Davis KJ, Elbers JA, Goldstein AH, Grelle A, Granier A, Guomundsson J, Hollinger D, Kowalski A, Katul G, Law B, Mali Y, Meyers T, Monson R, Munger JW, Oechel W, Paw UKT, Pilegard K, Rannik U, Rebmann C, Suyker AE, Valentini R, Wilson K and Wofsy S (2002) Seasonality of ecosystem respiration and gross primary production as derived from FLUXNET measurements. Agricultural and Forest Meteorology 78: 83-105.

Greco S and Baldocchi DD (1996) Seasonal variations of CO_2 and water vapour exchange rates over a temperate deciduous forest. Global Change Biology 2: 183-198.

Gu L, Baldocchi D, Verma SB, Black TA, Vesala T, Falge EM and Dowty PR (2002) Advantages of diffuse radiation for terrestrial ecosystem productivity. Journal of Geophysical Research D6 10.1029/200 1JD001242.

Hendriks DMD, Dolman AJ, van der Molen MK and van Huissteden J (2008) A compact and stable eddy covariance set-up for methane measurements using off-axis integrated cavit output spectroscopy. Atmos Chem Phys 8: 431-443.

Paw UKT, Baldocchi D, Meyers TP and Wilson KB (2000) Correction of eddy covariance measurements incorporating both advective effects and density fluxes. Boundary Layer Meteorol 97: 487-511.

Chapter 4

Measurement of Greenhouse Gas Emissions from Biomass Burning

N Jain, A Bhatia and H Pathak

Biomass fires associated with human activities such as forest and savanna burning, burning of agricultural residues, and domestic burning of biofuels, has a potential impact on global air quality and climate. Biomass burning is an important source of aerosol and gaseous pollution in the atmosphere. Gases produced by the biomass burning are carbon dioxide, carbon monoxide, methane, non-methane hydrocarbons, nitric oxide, nitrous oxide, and atmospheric particulates. Carbon dioxide, methane and nitrous oxide are the important greenhouse gases (GHGs), which have impact on global climate. Carbon monoxide, methane, non-methane hydrocarbons, volatile organic compounds and nitric oxide are chemically active gases that lead to the chemical production of ozone in the lower atmosphere or troposphere (Levine 1989). Volatile organic compounds (VOCs) are of high interest for atmospheric chemistry and biogeochemistry as they contribute to the oxidative capacity of the atmosphere, to particle production and to the carbon cycle.

Burning of agricultural residues, represent a significant source of chemically and radiatively important trace gases and aerosols into the atmosphere affecting the atmospheric composition. With the advent of mechanized combines, a large amount of crop waste generated is left in the fields. This residue is generally burned in-situ primarily to clear the remaining straw and stubble after the harvest inexpensively to prepare the land for the next growing season. The crop residues that are typically burned in India and in many other countries are rice, wheat, cotton, maize, millet, sugarcane, jute, pulses, rapeseed-mustard and groundnut. Crop residues burned is converted into gases, soot and particulate matter, aerosols and ash. The composition of the gases depends upon the burning conditions. Burning takes place in two phases: flaming and smoldering. During flaming phase the concentration of carbon dioxide is more whereas carbon monoxide concentration is more during smoldering phase.

Sampling and analysis of GHGs and air pollutants

Mainly there are three methods of sampling for gaseous and aerosol emissions from biomass burning.

(1) Ambient sampling

It involves the measurement of greenhouse gases (GHGs) and other hydrocarbons in the open atmosphere during the burning of biomass. The air sampling is done using steel canister/tedler bags, diaphragm sampling pump and air flow meter. The canister, also known as SUMA canisters should be cleaned by flushing thoroughly with nitrogen gas and evacuated prior to sampling. A fraction of air in each canister should be analyzed for gases of interest before use to ensure adequate cleaning. The sampling should be done in both upwind and downwind directions of the sampling location to know the change in concentration of gases due to burning. After sampling the canister/tedler bags are made air tight and brought to the laboratory for analysis on GC as discussed in Chapter 2.

(2) Plume sampling

Direct sampling in the smoky plume of a fire is a relatively difficult by the sampling crew. Many times sampling team that exhibit temporal shifts in the position of the flame front are not able to approach the uncontrolled fires due to frequent temporal shifts in the position of the flame front. Changing wind directions also makes it difficult to position the ambient sampling devices to collect a representative sample. To overcome these problems EPA has developed a Nomad sampler (Lemicux et al. 2004). The sampler consists of a hand-held boom that enables the sampling crew to insert the suction end of a sampling probe directly into the smoke plume without going very close to the smoke or fire. The Nomade consists of a TO-9 head and PUF/XAD/PUF (polyurethane foam/ non polar resin/ polyurethane foam) cartridge coupled with a high volume sampler, sampling train with scrubbers for SOx, and NOx. The TO9 head is connected to sampling inlet probe with an adapter. The sampling probe is attached to a light weight pole of approximately 10' so as to insert the probe in fire area conveniently during sampling. The GHGs and hydrocarbon samples can then be analyzed by GC as discussed in chapter 2 or GCMS. The SOx and NOx samples can be analyzed by colorimetric methods.

(3) Laboratory method

Quantification of ash produced after an open fire on the field is difficult and inaccurate, since the ash gets dispersed on the ground by wind or flames. Therefore an effective way to develop emission factors for open burning sources is through

laboratory simulations using a flux chamber approach. This is the most common method as the losses due to changing wind speed and wind direction are not there. Measurement of emissions from the enclosed laboratory facility in combination with dilution rate of incoming air for combustion and loss in weight during combustion gives the emission of that pollutant per unit of biomass burned. In flux chamber, small weighed quantity of the biomass is combusted in the steel drum/ or a steel trey of the chamber. Air flow inside the chamber can be controlled with the help of flow meters attached to the air passage. Gas sample can be collected with the help of a sampling probe, a filter holder, a diaphragm pump, and a Tedlar bag/steel canistars from the sample duct. The filters should be dried in oven at 70-80 °C for 24 hrs and stored in desicator prior to sampling. Tedlar bags/steel canisters should be flushed at least three- four times with clean air or nitrogen before use and sealed at the end of the sampling period. Air samples are then taken from the tedler bags/steel canisters using glass syringes and injected into a gas chromatograph (GC) fitted with ECD for nitrous oxide and FID for methane and FID with methaniser carbon dioxide analysis. Measurements of the mass of burning material, amount of combustion air and dilution air flow rates, and temperature inside the chamber should also be recorded. The GHG concentrations measured in the chamber can be converted to the mass emissions of individual GHGs (emission factor units) using following equation.

$$EF = (C_{sample} \, Q_{chamber} \, t) / M_{burned}$$

Where EF = the emission factor in mg/kg biomass consumed, C_{sample} = the concentration of the GHGs in the sample (mg/m^3), $Q_{chamber}$ = the flow rate of dilution air into the chamber in m^3/min), t = the burn sampling time in minutes, and m burned = the mass of biomass burned (kg).

References

Lemicux PM, Lutes CC and Santoianni DA (2004) Emissions of organic air toxics from open burning. A comprehensive review, Progress in Energy and Combustion. Science 30: 1-32.

Levine JS (1989) Photochemistry of biogenic gases. In MB Rambler, L Margulis and R Fester (eds.), Global Ecology: Towards a Science of the Biosphere. Academic, San Diego, California, USA, pp. 51-74.

Greenhouse Gas Emissions from Livestock

Chapter 5

Measurement of Greenhouse Gas Emissions from Livestock

RC Upadhyay, Madhu Mohini, SK Sirohi, AK Puniya, Smita Sirohi, SV Singh, Renuka, Jyoti D, Anil Kumar, Rajni Singh and Praveer Damle

Cattle and buffaloes are ruminants and have a distinctive digestive system that enables them to eat fibrous plants and in the process of digestion they produce methane. Since, the digestion or enteric fermentation is only 50-60 percent efficient, some of the feed energy (i.e., 4-15 percent) is lost in the form of methane a potent greenhouse gas. Animals maintained on high fibrous diets, release more methane and contribute to climate change. Methane is released into the atmosphere from animals routinely and contribution of ruminants is more than non-ruminants. The enteric fermentation is a natural process of digestion in both ruminants and non-ruminants, where anaerobic microbes i.e., methanogens decompose and ferment fibrous feeds. Methane, a byproduct of microbial digestion process, has a global warming potential 21-folds higher than that of carbon dioxide. The level of methane production in rumen is affected by the quantity and quality of the feed. As the amount of feed consumed increases, the energy available for conversion into methane also increases. However, as the feed digestibility increases, the portion of energy that is converted to methane decreases. In a highly digestible feed, only 3-6% of energy would be converted to methane and as the digestibility decreases, the energy loss as methane increases to 9 percent or more. The effective measures to mitigate enteric fermentation in ruminant system would not only help reduce emissions but also raise the productivity by improving the feed efficiency.

In this chapter the most common methods used for estimating and measuring methane emissions from animal particularly ruminants have been described. The main focus is on methods at the individual animal scale. Each method is presented and advantages and disadvantages are emphasized.

Measurement of methane by open circuit chambers

Animal chamber systems or respiration chambers have been developed for energy metabolism studies and used for the last 100 years. Methane is lost as a part of the energy and has been measured for metabolism in ruminants. Animal chamber facilitates collection of gases both in exhaled breath and appearing in the form of flatulence from the animal and help measure total methane concentration. Animal calorimetric systems, where air composition is measured, are of two types: The closed-circuit and the open-circuit. An outline of an open-circuit system used at NDRI is shown in Fig. 1. A pump is used to pump out air from the animal chamber, flow rate is measured either passing through a flow meter or a rotameter and concentration of different gases are measured by analyzers. Fresh air in the chamber for the animal is drawn from outside. In another animal chamber fresh air is also drawn through an air conditioning system to control humidity and temperature. The air flow rate and gas concentration in ingoing and outgoing air from the animal chamber are used for calculating methane emissions. The methane emission is calculated as the product of flow rate, time and average methane concentration (Upadhyay et al. 2008). The CH_4 analyzer system is very precise and sensitive to detect minor changes in gas concentration. The precision of methane analyzer is periodically checked with standard gases.
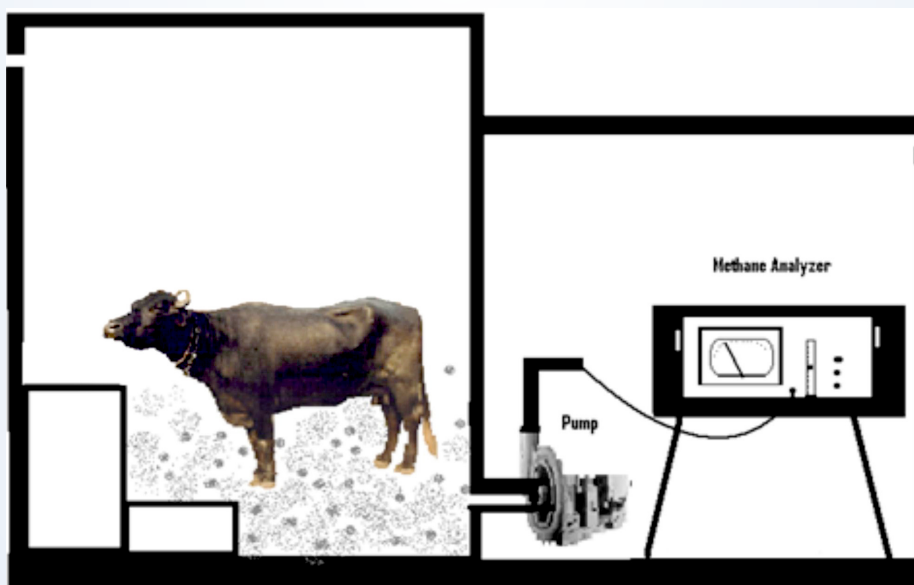

Fig. 1. Buffalo in animal chamber, pump and methane gas analysis system

Open circuit respiration chamber is regarded as the standard method for estimation of methane emission from ruminants, because the environment can be controlled and the reliability and stability of instruments can be measured. However, an artificial environment created by air conditioning may affect animal behavior and voluntary feed intake e.g. dry matter intake (DMI). Since, DMI is one of the main drivers of methane emission a change or decrease in DMI would not only affect total emission but also the derived estimates like loss of gross energy values. Therefore, it has been argued that results obtained in chambers cannot be applied to free ranging animals e.g., animals on pasture grazing. Investigations at NDRI have also been made using SF6 tracer technique. The estimates based on animal chambers are more precise estimates of methane emissions than the SF6 tracer technique (Mcginn 2006).

Classical animal chambers for energy metabolism with air conditioning, internal mixing of air and careful tightening to reduce the air loss to the surroundings are more expensive. Therefore less expensive systems have been developed with methane measurements as the main purpose. At NDRI animal chamber system is in use. Recently a prototype based on open circuit calorimetry has been built and tested. Fabrication of polycarbonate chambers are in process for energy metabolism studies and to facilitate precise monitoring of GHG emission from livestock production system. The animal chamber system permits investigation of nearly all aspects of feeding and nutrition. The level of feeding, effect of feeds and feeding stuff, effect of chemical and physical composition, restricted versus ad libitum feeding, different feeding schedules, different additives etc can be investigated and evaluated. The chamber system further help measure changes in emission during the day and at periodic intervals with small resolution otherwise not possible with other systems (Storm et al. 2012).

Measuring methane with the SF6 tracer technique

The method based on SF6 tracer is relatively a new technique and recent development on methane measurement (Johnson et al. 1994, 1997, 2007). The main objective of the method is to investigate energy efficacy in free ranging cattle, to facilitate measurements on free ranging animals because of limitations that results obtained in respiration chambers could not be applied to free ranging animals. The SF_6 method is in use at NDRI and NDDB in India (Singhal et al. 2005; Singh 2001). The basic principal of the method is that methane emission is proportional to the emission rate of SF6 tracer gas from the rumen. For this purpose SF_6 a non-toxic, physiologically inert, stable gas is used and the gas mixes with rumen air in the same way as methane. The SF6 has an extremely low detection limit and is simple

to analyze. In order to measure methane emission from animals SF6 is filled into small permeation tubes, the rate of diffusion of SF_6 from the permeation tubes is measured by placing them in a water bath at 39 °C temperature. The weight loss of permeation tube is measured daily until it is stable. The permeation tube is then placed in the rumen of an experimental animal i.e., cattle or buffalo and collection of expired air started. The sampling apparatus consists of a collection canister, a halter and capillary tubing. A capillary tube is placed at the nose of the animal and connected with the evacuated canister. The tubing regulates the sampling rate. The sampling time is normally one day, but emission estimates for shorter time intervals are possible. The concentration of SF_6 and CH_4 in the canister is determined by gas chromatography using suitable detection system. The GC system fitted with 1.0 cc sample loop to gas sampling valve, stainless steel column packed with Porapak N (3.17 mm ×1.22 mm), and a flame ionization detector. Sulfur hexafluoride is estimated with an electron capture detector (ECD). The system is calibrated with a series of SF_6 standards, ranging from about 30 to 1000 ppt SF_6. The SF_6 standards of different concentrations are used for routine checks.

Methane emission is calculated from the release rate of SF6 and concentration of SF_6 and CH_4 in the containers in excess of background level as described below.

$QCH_4 = QSF_6 \times (CH_4) / (SF_6)$

CH_4 (g hr-1) = SF_6 release rate (g/h) $\times CH_4$ g/m^3/SF_6 g/m^3

Fig. 2. Neck halter and capillary tube system on nostril area for measuring SF_6

Background concentrations of methane and sulfur hexafluoride should be always deducted from the concentration of these gases measured in the collection canister. The background SF_6 concentrations are normally very small compared to canister concentrations and therefore, shall usually be neglected. But the background methane levels (-2 ppm; (CH_4) b) should be subtracted from the methane concentration measured in the canister $((CH_4)$ y):

$$QCH_4 = QSF_6 \times (CH_4)y - ((CH_4)b)/SF_6$$

The method has been tested during the last two decades. A number of difficulties have been observed and are as follows. Maintaining a constant release rate from permeation tubes, effect of release rate upon emission rate of methane, background level determination, inconsistency between methane measurements determined in chambers and with SF6 and within and between animal variation (Mcginn 2006, Pinares-Patiño and Clark 2007, Storm et al. 2012).

The release rate is important and affects emission estimates if not correctly determined. The release rate from permeation tubes is determined under laboratory conditions by weighing the permeation tubes regularly for at least 1½ months. Only highly linear permeation tubes are used ($R^2 > 0.997$). However, permeation curves have been shown to be slightly curvilinear under laboratory conditions. Tests of permeation tubes pre- and post-experiments have also shown differences in permeation rate. The permeation tubes are weighted in a laboratory in dry air and the release rate should be the same in the rumen. However, a 6–11% lower release rate in tubes placed in rumen fluid than in air has been observed.

A lower methane emission (7%) with the SF6 technique than with chambers in cattle was observed (Johnson et al. 2007) due to limitation of chamber as the procedure takes in to account only expired or eructated gases from mouth. Comparative studies have (Mcginn 2006, Pinares-Patiño et al. 2007) also showed a slightly lower emission (5–10%) with the SF6 technique than with chambers for both cattle and sheep. However, slightly higher values with the SF6 technique have been shown than chambers, and yet other studies have found much higher values with the SF_6 technique than chambers (Pinares-Patiño et al. 2008).

In vitro gas production measurement

The high quality glass syringes for in vitro analysis are used (Menke and Steingass 1988). All substrates to be tested should be milled using a 1mm screen. Weigh 200 mg of substrate into each (numbered) syringe and actual weight is recorded. In each set of experiment blank is include (i.e. rumen fluid/artificial saliva mixture on

its own) at the beginning, in the middle of the set, and at the end. A control sample is added in each run to correct for possible variations between runs. All samples are done in duplicate or triplicate. After weighing is completed, the plungers are greased with vaseline and placed in incubator at 39°C. This is normally done one day before the actual run.

Preparation of Artificial Saliva is done prior and distilled water, buffer solution, macromineral solution, micromineral solution and resazurin solution are added into a round flat-bottomed flask. Warm to 39°C then add reducing solution (Menke KH & Steingass H 1988). Place water bath set at 39°C on magnetic stirrer, put magnet into flask and gently bubble CO_2 into the solution until the blue color turns to pink then clear – this means the artificial saliva is now reduced. Raise the CO_2 tube so that it will be above the level of the artificial saliva/rumen fluid mixture, but providing a stream of CO_2 and an O_2–free atmosphere, buffer should be pH 7.0-7.3.

On the day of actual run collect rumen fluid from the animals (normally 2 or 3), strain rumen liquid through three layers of gauze; the final ratio of artificial saliva : rumen fluid should be 2:1. Pour the strained rumen liquid into the artificial saliva. Make sure the magnet is stirring properly during the whole process of dispensing the rumen fluid/artificial saliva into the syringes.

Add 30 ml solution to each syringe using a dispenser. Fill the syringe, then open the clip and gently push the syringe's plunger so that all the air is removed. Record the volume and place in water bath. Readings can be taken to suit the type of substrate in the syringes. For forages 3, 6, 12, 24, 48, 72 and 96 hr are suitable but for concentrate substrates it may be necessary to take more readings in the first 24hrs. It is advisable to gently mix each syringe 2-3 times during the first day as well as each time a reading is taken.

References

Johnson K, Huyler M, Westberg H, Lamb B, Zimmerman P (1994) Measurement of methane emissions from ruminant livestock using a SF6 tracer technique. Environ Sci Technol 28: 359-362.

Johnson KA, Huyler M, Pierce CS, Westberg H, Lamb B, Zimmerman P (1992) The use of SF6 as an inert gas tracer for use in methane measurements. J Anim Sci 70: 302.

Johnson KA, Westberg HH, Michal JJ, Cossalman MW (2007) The SF6 Tracer Technique: Methane Measurement from Ruminants. In Measuring Methane Production from Ruminants; Makkar HPS, Vercoe PE (Eds.) Springer: Dordrecht, The Netherlands.

Mcginn SM, Beauchemin KA, Iwaasa AD, McAllister TA (2006) Assessment of the sulfur hexafluoride (SF6) tracer technique for measuring enteric methane emissions from cattle. J Environ Qual 35: 1686–1691.

Menke KH and Steingass H (1988) Estimation of the energetic feed value obtained from chemical analysis and in vitro gas production using rumen fluid. Animal Res Dev 28: 119-127.

Pinares-Patiño CS and Clark H (2008) Reliability of the sulfur hexafluoride tracer technique for methane emission measurement from individual animals: An overview. Aust J Exp Agric 48: 223–229.

Pinares-Patiño CS, D'Hour P, Jouany JP and Martin C (2007) Effects of stocking rate on methane and carbon dioxide emissions from grazing cattle. Agric Ecosyst Environ 121: 30–46.

Pinares-Patiño CS, Machmuller A, Molano G, Smith A Vlaming JB and Clark H (2008) The SF6 tracer technique for measurements of methane emission from cattle-Effect of tracer permeation rate. Canadian J Anim Sci 88: 309-320.

Ranjhan SK (1999) Animal Nutrition and Feeding Practices; Vikas Publishing House, New Delhi.

Singh G (1999) Characteristics and use of draught animals power in India. Indian J Animal Sci 69 (8): 621–627.

Singh GP (2001) Livestock Production and Environmental Protection. Proc.: X Animal Nutritional Conference, Karnal 211-222.

Singhal KK, Mohini, Madhu, Jha AK and Gupta PK (2005) Methane emission estimates from enteric fermentation in Indian Livestock: Dry matter intake approach. Curr Sci 88: 119-127.

Storm IMLD, Hellwing ALF, Nielsen NI and Madsen J (2012) Methods for Measuring and Estimating Methane Emission from Ruminants. Animals 2: 160-183.

Upadhyay RC, Gupta SK, Kumar A, Singh SV and Ashutosh (2008) The contribution of draught animals to methane emission in India. Draught Animal News, 46:29-36.

Greenhouse Gas Emissions from Aquaculture

Chapter 6

Measurement of Greenhouse Gas Emissions from Aquaculture

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Aquaculture like agriculture is an important anthropogenic source of greenhouse gases emission. With the kind of stocking density and the high quantity of different inputs being added into the aquaculture ponds for the profitable culture of species, it is for certain that they would add up to the current greenhouse gases (GHGs) concentration in the atmosphere. About 16.6 million tons of carbon is annually buried in aquaculture ponds globally. This is about half the amount sequestered by natural lakes and inland seas (Boyd 2010). The global N_2O-N emission from aquaculture in 2009 is estimated to be 9.30 ×1010 g and will increase to 3.83 × 1011 g which could account for 5.72% of anthropogenic N_2O-N emission by 2030 if the aquaculture industry continues to increase at the present annual growth rate of 7.10% (Zhen et al. 2012). These facts clearly suggest that the emission of GHGs from the aquaculture ponds is an issue or concern.

In general, ponds represent a net source of CO_2 to the atmosphere (Sobek et al. 2005) and they are now recognized as important contributors to regional and global climate (Cole et al. 2007). Based on the life cycle analysis, of all aquaculture commodities, shrimp culture consumes a lot of energy (De Silva and Soto 2010) and therefore possibly emits more GHGs. CH_4, N_2O and CO_2 from aquaculture pond are brought into the water column and then into atmosphere through diffusion mainly by methanogenesis, nitrification and denitrification processes in the pond bottom sediments.

There are no methodologies available for the direct estimation of GHGs from the aquaculture ponds and this has stimulated the research to develop, standardise and estimate the emission of GHGs from the aquaculture ponds.

Greenhouse gas emission from aquaculture sector

Closed-chamber method

A cylindrical acrylic chamber with a float can be used to trap the GHGs emanating from the surface of aquaculture pond water (Fig. 1). The height and radius of the chamber are 42 and 15 cm respectively. The closed chamber system is constructed of chemically inert material. The chamber is designed with an open ended bottom that can penetrate water to a depth of 7 cm, thus forming a seal between the water surface and the air within the chamber and thereby proving a completely enclosed system to measure gaseous fluxes. The floating chamber is connected with air sampling pump (SKC universal, PCXR8 model) and Tedlar bag via three way stop cock by silicon tubing. This method measures the gas accumulation in a closed compartment (chamber) floating at the surface of the water.

Collection and analysis of gas samples

The chamber is allowed to float freely in the pond and the samples are to be collected at different time intervals in tedlar bags. The inlet and outlet of chamber, air sampling pump and tedlar bag are connected by silicon tubing via three way stopcock. The suction of air from the inlet and discharge into the outlet of the chamber by the air sampling pump allows effective mixing of the gas sample. The GHGs sample is then discharged into the tedlar bag by the shifting of valves in the three way stopcock (Fig. 1). The GHGs fluxes collected at different time intervals in different tedlar bags are to be transported to the laboratory in ice cool box for analysis by GC system with Headspace within 72 hours. The GHGs are quantified based on the standard GHGs response in the chromatogram.

Floating GHGs sampler   Collection of gases with air sampling pump

Fig. 1. Sampler for collection of greenhouse gas samples from aquatic systems

Gas flux gradients are calculated using the gas sample concentrations of the sampled air, over a time sequence, from the floating chamber on the aquaculture pond. Gas sampling time is determined by the rate of build- up of the gases in the headspace of the chamber. The emission of GHGs are calculated using the equation

$$\text{GHG flux (mg m}^{-2}\,\text{h}^{-1}) = \frac{\Delta X \times \text{ECV (STP)} \times \text{MW} \times 1000 \times 60}{10^6 \times 22400 \times T \times A}$$

Where, ΔX = Difference in flux value between 60 min and 0 min (converted to ppm based on the standard CH_4 or CO_2 values & ppb based on the standard N_2O values), ECV (STP) = Effective chamber volume at standard temperature and pressure, MW = Molecular weight of the GHG, T = Flux time (min.), A = Area of chamber

Precautions and limitations of the method

Precautions

- The floating of the chamber should be monitored carefully so that it would not topple.

- There should not be any leakage of gas from the chamber.

- Water should not enter into the air sampling pump while sampling the GHGs.

Limitation

- The stability of the GHGs sample is time specific and cannot be stored for long.

Measurement of carbon dioxide emission from soil

Closed-chamber method

The closed-chamber method according to Smith et al. (1995) was used for the determination of soil CO_2 efflux. Cylindrical chamber of inside diameter 40 cm and height 20 cm are closed with a aluminum sheet, with a rubber seal and sampling port fitted with three way stopcock. The chambers are left permanently in the field in order to minimize the effects caused by insertion in the soil. After having kept the cylinders for an hour, air samples from inside the chamber are taken with 60 ml syringes. These samples are transferred to the laboratory and analysed for the concentration by gas chromatograph. The exchange rate of CO_2

across the soil atmosphere is largely the function of diffusion coefficient and concentration gradient between the site of production and soil surface (Hutchinson and Livingston 1993).

$$F_3 = d\,\frac{V}{A} \times \frac{(C_2 - C_0)}{t}$$

Where,

F is the soil CO_2 efflux

d is gas density

C_t is the concentration of CO_2 at time t

C_0 is the intial concentration

V is the volume of the chamber

A is the area of the chamber and

t is the time of deployment.

i) Culture ponds

Nakadai et al. (1993) reviewed the methods of soil respiration measurement in cultivated lands and studied the effect of carbon dioxide concentration on soil respiration.

Soil respiration chamber: Alkali trap laboratory method

- Collect the soil samples from ponds from the upper 5 cm soil layer with aid of a 5 cm diameter, PVC soil core tube.

- Dry the soil samples in an oven (60 ^{0}C) for 3 days and ground to 0.25 mm particle size (Use mechanical sieves).

- Place 5-cm deep layer of soil (known wt. of soil i.e., 15 g soil) on the plain surface. A 12 cm diameter x 5 cm tall plastic jar was suspended 5 cm above soil surfaces on wire supports, and pipette 20 ml of 1 N NaOH into these small jars.

- Cover the complete setup with 25 cm diameter by 30 cm tall glass jars as respiration chambers and seal the chambers with a lid (air-tight). Carbon dioxide released in soil respiration is absorbed by sodium hydroxide.

- After 24-hour exposure, remove the jars of sodium hydroxide from chambers and tightly cap them to form an air-tight seal. After allowing 15 min for air exchange, replace the lids on respiration chambers to prevent soil from drying.

- Add an excess of 3 N $BaCl_2$ solution to the sodium hydroxide to precipitate carbonate in 25-ml centrifuge tubes. Separate the supernatant containing remnant sodium hydroxide from precipitate by centrifugation at 2,500 rpm and estimate the amount of carbon dioxide evolved in soil respiration by titration with 1 N HCl.

- Respiration chambers with no soil are taken as controls.

ii) Fallow period (In situ - Harvested pond bottom soil)

a) Soda lime method

- After harvest of the crop, select a small area in the pond (preferably similar place, where studied during culture period). Do in triplicate at each location.

- Take approximately 8 grams of soda lime (white or grayish white granular mixture of calcium hydroxide with sodium hydroxide or potassium hydroxide) in each 25 to 50 ml small glass jars. Label each glass jar with a piece of tape and permanent marker.

- Place the jars with soda lime in oven at 105 °C for at least 24 hours to evaporate the water from the granules (Drying takes 24 to 48 hours). (Precaution: Soda lime is slightly caustic and one has to be careful in handling)

- On the day of the experiment, remove jars from the oven and place in a desiccators to cool for 2 to 5 minutes.

- Remove jars from the desiccator one at a time, weigh to the nearest tenth-milligram (0.0001 g) and cover immediately. Record this weight as pre-incubation dry mass that includes the soda lime and jar.

- Place a chamber (may be of plastic) upside down on a relatively flat area of the pond bottom. The rim of the plastic chamber must make an air tight seal with the soil surface, so carefully remove small rocks and other waster that are in the way without disturbing the soil surface under the chamber. Leave the chamber loose on the surface for now.

- Remove the cap of soda lime jar and place the jar under the chamber resting on the soil. Make sure it is not likely to fall down.

- Slowly and carefully push down on and rotate the plastic chamber to force the edges about 0.5 to 1 cm into the pond bottom floor. Place a weight on the chamber (like a medium-sized rock) to maintain pressure and keep it from blowing away (Fig. 2).
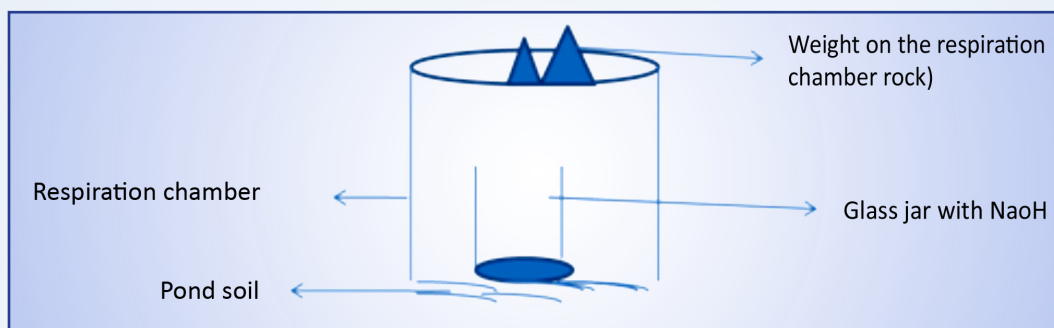
Fig. 2. Respiration chamber setup on the pond soil during fallow period

- Record the number of the soda lime jar and the number and location of the chamber. Repeat these steps for each of the chambers at each site.

- At one of the sites, place an opened jar of soda lime in an upright chamber and seal the chamber with a lid. This will serve as a blank to document the amount of CO_2 absorbed from the air in the chamber and during the opening and closing of the jars.

- Incubate all the chambers for 24 to 48 hours.

- Collect the soda lime jars from the field. Remove the chamber and cover the soda lime jar. Measure and record the air temperature, soil temperature and soil water content.

- Place all the jars uncovered in the oven at 105 °C. Dry for at least 24 hours to evaporate water from the soda lime.

- Remove the dry soda lime jars from the oven and place in a desiccator to cool for 5 minutes. Remove jars one at a time from the desiccator, weigh to the nearest tenth-milligram. Record this as the post-incubation dry mass (which includes the mass of the jar).

b) *Alkali trap method*

This is same as that of method used for soil samples during culture period. Keep the jars in the pond and take 1 N NaOH solution and the other procedure is similar.

References

Boyd CE (2010) Aquaculture ponds hold carbon. Global aquaculture advocate, monthly digital magazine, March/April, 23-24.

Cole JJ, Prairie YT, Carcao NF, Mc DSowell WH, Tranvik LJ, Striegl RG, Duarte CM, Kortelainen P, Downing Ja and Melack J (2007) Plumbing the global carbon cycle: integrating inland waters into the terrestrial carbon budget. Ecosystems 10: 171-184.

Hutchinson GL and Livingston GP (1993) Use of chamber systems to measure trace gas fluxes. In: Agricultural Ecosystem Effects on Trace Gases and Global Climate Change. Harper LA, Mosier AR, Duxbury JM, Rolston DE (eds.), vol. 55, American Society of Agronomy, Crop Science Society of America and Soil Science Society of America, Madison, Wisconsin, pp. 63-78.

Nakadai T, Koizumi H, Usami Y, Satoh M and Oikawa T (1993) Examination of the methods for measuring soil respiration in cultivated land: Effect of carbon dioxide concentration on soil respiration. Ecol Res 8: 65-71.

De Silva SS and Soto D (2010) Climate change and aquaculture: potential impacts, adaptation and mitigation. FAO Fisheries and Aquaculture technical Paper. No. 530, Rome, FAO. pp. 151-212.

Smith KA, Clayton H, Mc Taggart IP, Arah JRM and Scott A (1995) The measurements of nitrous oxide from soil using chambers. Philo Trans Royal Soc London, Series A, 351: 327-338.

Sobek SL, Tranvik J and Cole JJ (2005) Temperature independence of carbon dioxide super-saturation in global lakes. Global Biogeochem Cycles 19:doi: 10.1029/2004GB002264.

Zhen H, Jae WL, Kartik C, Sungpyo K and Khanal SK (2012) Nitrous oxide emission from aquaculture: A Review, ACS publications. Environ Sci Technol 46(12): 6470–6480.

Life-Cycle Analysis of Greenhouse Gas Emissions

Chapter 7

Greenhouse Gas Emissions from Rice and Wheat Production Systems - A Life Cycle Assessment

N Jain, M Muralidhar, A Bhatia and H Pathak

Food consumption in relation to environmental impact has received political and social attention in recent years. Research into the environmental effects of food consumption usually focuses on energy use and the production of waste and rarely has been evaluated for greenhouse gases (GHGs) emission. From the view of food consumption, carbon dioxide (CO_2) is the most important GHG followed by methane (CH_4) and nitrous oxide (N_2O) (Krammer et al. 1999). Fuel combustion activities are the main sources of CO_2 emission, whereas animal husbandry and rice cultivation are the main sources of CH_4 emission, and the emission of N_2O is mainly from turnover of nitrogen in soil, application of N fertilizer and industry.

Food production systems as a group are very heterogeneous. The range of products is huge and production systems vary within product groups as well. However, there are some common traits. For the production of food crops (e.g. cereals, pulses and oilseeds), emissions of CO_2 from fossil fuel use in various operations is less important than for most other industrial products, instead emissions of biogenic GHGs are more important for crop production. Products of animal origin, such as meat and dairy, have on average higher emissions per kilogram than vegetable products, but there are many exceptions (Pathak et al. 2010). Meat and dairy production contributes to approximately 18% of global GHGs emissions. Transport of food products plays an important role in GHGs emission. Food waste ending up in landfills are also an important contribution to GHGs emissions, methane is formed when food is degraded under anaerobic conditions in the landfills. Packaging can be of significance, but it is a trade-off between role of the packaging for protecting the food and emissions of the packaging material.

Society has become more concerned about the issues of natural resource depletion and environmental degradation due to increased awareness. It is thus essential to evaluate the environmental impact and the utilization of resources in

food production and distribution systems for sustainable consumption. In recent years Life cycle assessment (LCA) has become an increasingly common approach across different industries, including agriculture, for environmental impact assessment. LCA was developed for the manufacturing sector and has since been applied to the agricultural sector (Brock et al. 2012). There is a need for analysis of the impacts of different agricultural production systems on GHGs emissions and how management practices affect these emissions. The LCA is a tool for evaluating and generating environmental information about a product, accounting for all resources consumed, all wastes generated, and the emissions to the environment of a product, process, or activity throughout its life cycle, which is also known as a 'cradle to grave' analysis (Arvanitoyannis 2008). "Cradle-to-grave" begins with the collection of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. LCA evaluates all stages of a product's life from the perspective that they are interdependent and one operation leads to the next (Roy et al. 2009).). Product and process evaluations may be based on Life Cycle Assessment in order to account for all environmental impacts of the product assessed. The LCA assessments are supposed to give valuable information of pollution loads like leaching of pollutants resulting in acidification of water bodies and eutrophication in agriculture and their possible ways of reduction through development of cleaner technologies (Breiling et al. 1999).

According to the International Organization of Standardization (ISO), LCA is divided into four phases: goal and scope definition, inventory analysis, life cycle impact assessment and interpretation (ISO14040 2006).

Goal definition and scoping

This is the first and a very important step of LCA because it defines the purpose, expected product, system boundaries, functional unit (FU) and assumptions of the study (Fig. 1). For LCA studies in the agricultural sector this could be for instance to investigate the environmental impacts of emissions in crop production or to analyze the advantages and disadvantages of different farming systems. System boundaries are generally presented in the form of an input and output flow diagram. All operations that contribute to the life cycle of the product, process, or activity fall within the system boundaries (Roy et al. 2009). The FU determines equivalence between systems. It is defined as the reference unit to which the inventory data is normalized. It is generally based on the mass of the product under study. Choosing a functional unit is not always straightforward and can have a profound impact on the results of the study.
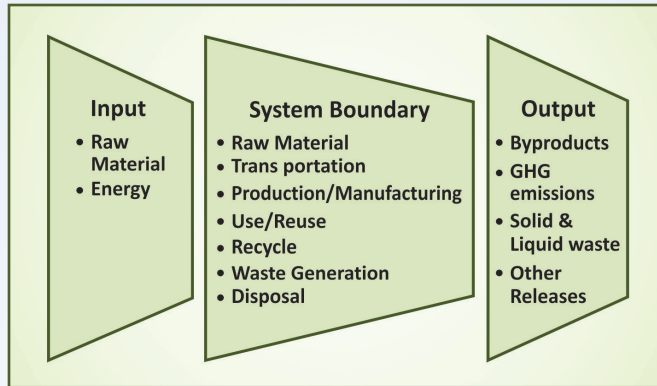
Fig. 1. Different stages of life cycle assessment (Adapted from Gillani et al. 2010)

Inventory analysis

This phase is the most work intensive and time consuming compared to other phases in an LCA. The step involves collection of data and quantification of the use of resources and energy as well as the environmental releases associated with the system being evaluated. The data collection is a strategic point in order to go through a valid and robust analysis and then to result in high-quality decisions (Gilani 2010). Every data entering the system (like raw materials, water, fuels and other inputs) or coming out to the environment (products, emissions, effluents, by-products and wastes) is quantified. This database is the input to the Impact Assessment stage. The impact assessment is done by calculations done according to specific methodology and the assumptions defined in the Goal and Scope stage. The inputs for all the subsystems are used for calculating the mass balance of all the overall system. The basic flow diagram of inventory analysis in LCA is depicted in Fig. 2. The elementary flows associated with the life cycle of the product system that generates the reference flow are to be quantified. These are the material and energy inputs and waste and emission outputs of all economic processes that are within the system boundaries.

Impact assessment

The impact assessment phase of an LCA is defined as "a quantitative and/or qualitative process to identify, characterize and assess the potential impacts of the environmental burdens identified in the inventory analysis" to understand their environmental importance and to estimate the possible environmental impacts on different categories (atmosphere, resource depletion, human, etc.) in
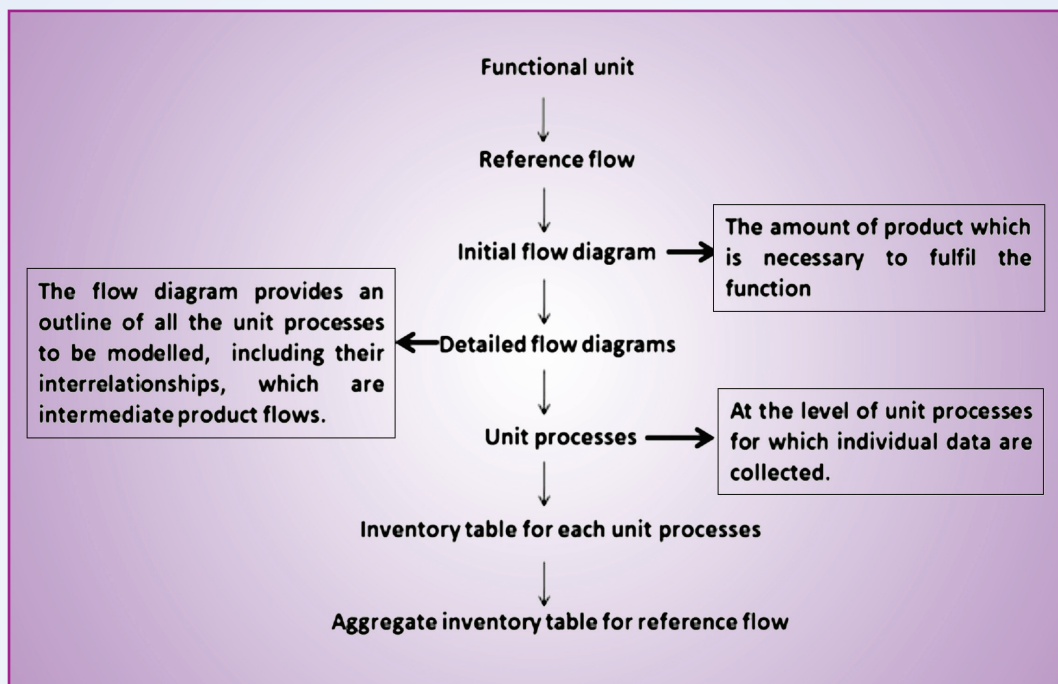
Fig. 2. Basic flow diagram of inventory analysis in the life cycle assessment

relation to various inputs and outputs. The categories are selected on the basis of the existing inventory data, expert judgment about cause-effect relationships and the assigning inventory data into the different impact categories. This step of the impact assessment is called Classification. The second step is the characterization step, in which analysis/quantification, of the impacts within the selected impact categories is done and is transformed to results called "environmental profile. The final step is the valuation (assigning weight) of different impact categories so as to compare them amongst themselves.

Interpretation

The purpose of an LCA is to draw conclusions that can support a decision or can provide a readily understandable result of an LCA (Roy et al. 2009). During this step, results of the other steps are interpreted according to the goal of the study. ISO and other sources define an interpretation component, as being the final component of the impact assessment (Huppes et al. 2010).

Methodology of LCA is explained by using an example of rice and wheat crops which are the two most important crops in India.

Life cycle assessment of rice-wheat

A single-issue LCA focusing on greenhouse gas emissions was conducted to determine the emissions profile and total carbon footprint of rice and wheat production India. Greenhouse gas emissions (in carbon dioxide equivalents; CO_2 eq.) from all stages of the production process, both pre-farm and on-farm, were included.

Goal of this study is to investigate the life cycle of rice and wheat and to assess environmental impacts of production, processing, packaging, marketing and consumption in India to assess if the greenhouse gas emissions can be decreased by changes in various processes. Various components and stages of the life cycle as well as system boundaries (direct and indirect) that are associated with GHGs emission are given in Fig. 3 and 4 (Pathak et al. 2012). All stages of production

Stages	Process	Equipment	Input	GHG
Production	Tillage	Tractor/Power tiller	Diesel	CO_2
		Bullock	-	CH_4
	Sowing	Seed drill	Diesel	CO_2
		Manual	-	-
	Transplanting	Manual	-	-
	Irrigation	Pump	Diesel/electricity	CO_2
	Fertilizer production	Factory	Electricity	CO_2
	Fertilizer application	Fertilizer drill	Diesel	CO_2
		Manual	-	-
	Biocide production	Factory	Electricity	CO_2
	Biocide application	Sprayer	-	-
	Soil microbial processes	-	-	$CH_4/N_2O/CO_2$
	Harvesting	Combine	Diesel	CO_2
		Manual	-	-
Processing	Drying	Sun drying	-	
		Machine dryer	Electricity	CO_2
	Milling (parboiling)	Stove	Biomass	CO_2
		Rice mill	Electricity	CO_2
Marketing	Packaging	Bag	Electricity	CO_2
	Transporting	Truck/Rail	Diesel/electricity	CO_2
	Storing	Warehouse	Electricity	CO_2
Consumption	Cooking	Oven	Gas/Electricity	CO_2

Fig. 3. Schematic diagram of different steps and processes in the life cycle of rice production system

Stages	Process	Equipment	Input	GHG
Production	Tillage	Tractor/Power tiller	Diesel	CO_2
		Bullock	-	CH_4
	Sowing	Seed drill	Diesel	CO_2
		Manual	-	-
	Irrigation	Pump	Diesel/electricity	CO_2
	Fertilizer production	Factory	Electricity	CO_2
	Fertilizer application	Fertilizer drill	Diesel	CO_2
		Manual	-	-
	Biocide production	Factory	Electricity	CO_2
	Biocide application	Sprayer	-	-
	Harvesting	Combine	Diesel	CO_2
		Manual	-	-
Processing	Drying	Sun drying	-	
	Milling	Mill	Electricity	CO_2
Marketing	Packaging	Bag	Electricity	CO_2
	Transporting	Truck/Rail	Diesel/electricity	CO_2
	Storing	Warehouse	Electricity	CO_2
Consumption	Cooking	Bakery	Electricity	CO_2
		Chapati	Gas	CO_2

Fig. 4. Schematic diagram of different steps and processes in the life cycle of wheat production system

including tillage, inter-culture and harvesting and activities related to post-harvest storage and processing prior to its entry into the trading system for sales to final consumers were identified. In addition, we included the indirect contribution to GHGs emission by fertilizer and pesticide manufacturing. It has been reported that agricultural LCA often excludes production processes of insecticides, machines, buildings, and roads due to lack of data (Cederberg and Mattsson 2000).

Production

The fields are typically ploughed before seeding of rice/wheat, the plough being drawn by a diesel-powered tractor or bullocks. Direct seeding is done in the case of wheat, while in the rice fields it is done either by direct seeding or manual seedling transplantation. After seeding, irrigation is done using a diesel-powered pump. For rice crop, the field is flooded with water which leads to anaerobic conditions, consequently methane gas is produced. Fertilizer is applied to the wheat/rice fields after irrigation. Nitrogenous fertilizers lead to the emission of nitrous oxide from the soils.

Harvesting and post-harvest activities

After maturity, the crop is harvested by combine harvesters and threshers. Combine harvester is operated by 60-75 kW engines. Pedal and power operated are the two main types of paddy threshers. These threshers are operated by 5-10 HP electric motor or diesel engine and tractor. Work capacity of pedal threshers is 40-50 kg/hr, while power-operated threshers' capacity varies from 200 to 1300 kg/hr. The paddy threshed by manual beating or by pedal-operated paddy thresher is cleaned by using hand/power-operated winnowing fans. Cleaned paddy (on an average) yields 72% rice, 22% husk and 6% bran. After harvesting, paddy is dried to reduce its moisture content to 14% (Fig. 3). Drying is done either under shade or by means of mechanical drier in which forcing heated or unheated air through the paddy in a bin or thin moving stream is used. Remaining impurities like pieces of stones, dust, lumps of mud, etc. are removed by winnowing. After cleaning, parboiling is done by soaking paddy in water for a short time, followed by heating once or twice in steam and drying before milling. Milling is done to remove the husk and retain a specified percentage of bran from the seeds. Rice milling includes hand pounding which involves pounding of paddy with hand stone or poles, whereas raw milling and parboiled rice milling is performed through huller, sheller or rubber roller mills. Rice husk is the largest by-product of rice milling industry which amounts to 22-24% of the total paddy. The heating value of husk has been reported to be 13 MJ kg^{-1} (3000-3500 kcal kg^{-1}). Husk is used for generating steam for parboiling paddy and as heat source mechanical dryers (Nayak 1996). Paddy/rice is transported from field to the market and from market to the consumers by bullock cart, tractor trolley, trucks, railway wagons, rickshaw and bicycle (http://agmarknet.nic.in/rice-paddy-profile_copy.pdf). The average transport distance was assumed to be 1000 km and 100 km in the upper-IGP and lower-IGP regions, respectively using a diesel-powered vehicle.

Wheat does not undergo as many steps of processing as rice after harvesting (Fig. 4). It is marketed after drying as raw wheat from the farms and then milled for flour or non-flour products. Of the total wheat production, 80% is milled into two broad product categories, viz. ~90% into whole-wheat flour (atta) and remaining into non-atta products, such as refined wheat flour (maida), semolina (suji) and bran (http://ceodifference.org/mgi/reports/pdfs/india/Wheatmilling.pdf). Most of the wheat flour is consumed directly by households to prepare unleavened Indian bread (chapattis). Wheat flour is milled in two formats: nearly 98% is milled in simple, electrically operated grinder called chakkis and the remaining is milled in modern industrial mills. A third format, manual grinding at home, is now almost obsolete. Marketing of wheat also involves transportation by bullock cart, tractor

trolley, trucks, railway wagons, rickshaw and bicycle at different stages (http://agmarknet.nic.in). The average transportation distance for wheat was considered 250 km and 1000 km in the upper-IGP and lower-IGP regions, respectively using a diesel-powered vehicle. The post-harvest losses of rice are estimated to the tune of 8-10% of production.

Packaging and marketing

Packaging of food is the vital step in ensuring longer shelf-life and preservation of quality and provision of protection against deterioration and damage during transportation and storage. The Government of India has made it obligatory to pack entire food grains in jute bags only. In the distribution of rice and wheat, the means and cost of transportation play an important role. The jute bags are transported in bulk from field to market by means of bullock carts, tractor trolley, truck and railways wagons.

Emission of GHGs during life-cycles of rice and wheat

The InfoRCT simulation model (Pathak et al. 2011) was used to calculate GHGs emission during production of rice and wheat. The model requires input data pertaining to amounts of fertilizer, irrigation water, biocides and machine labor. The GHGs emission during post-harvest processing (drying, milling), transportation, packaging and marketing of wheat and rice was calculated using energy consumption at each step. A conversion factor of 0.022 kg CGJ^{-1} and 0.025 kg CGJ^{-1} was used for carbon emission from fossil fuel burning and coal burning, respectively (Manaloor and Sen 2009).

References

Arvanitoyannis IS (2008) ISO 14040: Life Cycle Assessment (LCA) —Principles and Guidelines. Waste Management for the Food Industries. SA Ioannis, Dr and Ph.D. Amsterdam, Academic Press: 97-132.

Breiling M, Tatsuo H and Matsuhashi R (1999) Contribution of rice production to Japanese greenhouse gas emissions applying life cycle assessment as a methodology. University of Tokyo, Japan. www.landscape.tuwien.ac.at/lva.

Brock P, Madden P, Schwenke G and Herridge D (2012) Greenhouse gas emissions profile for 1 tonne of wheat produced in Central Zone (East) New South Wales: a life cycle assessment approach. Crop Pasture Sci 63: 319–329.

Cederberg C and Mattsson B (2000) Life cycle assessment of milk production - a comparison of conventional and organic farming. J Cleaner Prod 8: 49–60.

Gillani ST, Belaud JP, Sablayrolles C, Vignoles M, Le L and Jean M (2010) Review of Life Cycle Assessment in Agro-Chemical Processes. Chemical Product Process Modeling 5(1): 1-26.

ISO (2006) Report of the International Organization for Standardization 14040:2006 (E) Environmental Management – Life Cycle Assessment – Principles and Framework, p. 1-20.

Kramer KJ, Moll HC, Nonhebel S, Wilting HC (1999) Greenhouse gas emissions related to Dutch food consumption. Energy Policy 27: 203–216.

Manaloor V and Sen C (2009) Energy input use and CO2 emissions in the major wheat growing regions of India. Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China, 16-22 August.

Nayak P (1996) Problems and prospects of rice mill modernization A case study. J Assam Univ 1(1): 22-28.

Pathak H, Aggarwal T and Jain N (2012) Greenhouse gas emission from rice and wheat systems: A life-cycle assessment. In Pathak H and Aggarwal PK (Eds.) Low Carbon Technologies for Agriculture: A Study on Rice and Wheat Systems in the Indo-Gangetic Plains. Indian Agricultural Research Institute, p. xvii + 78.

Pathak H, Jain N, Bhatia A, Patel J and Aggarwal PK (2010) Carbon footprints of Indian food items. Agric Ecosys Environ 139: 66–73.

Pathak H, Saharawat YS, Gathala M and Ladha JK (2011) Impact of resource-conserving technologies on productivity and greenhouse gas emission in rice-wheat system. Greenhouse Gas Sci Tech 1: 261–277.

Roy P, Nei D, Orikasa T, Xu Q, Okadome H, Nakamura N, Shiina T (2009) A review of life cycle assessment (LCA) on some food products. J Food Engin 90: 1–10.

Chapter 8

Greenhouse Gas Emissions from Aquaculture Sector - A Life Cycle Assessment

**M Muralidhar, P C Das, M Kumaran, M Jayanthi, R Saraswathy
J Ashok Kumar, J Syama Dayal and A Panigrahi**

Measuring and understanding the greenhouse gases (GHGs) emissions, or carbon footprint of fishery and aquaculture-derived products is an important part of the seafood industry's efforts to alleviate environmental burden and improve long-term environmental and economic sustainability. To this end, life cycle assessment (LCA) has been increasingly applied in recent years to analyze the emissions of GHGs, as well as other substances of environmental concern, associated with seafood supply chains (Pelletier and Tyedmers, 2008; Thrane et al. 2009). Case studies of aquaculture production systems have typically included feed production and farm activities, often broken down by sub-processes (e.g. electricity use, chemical inputs, etc.). Less commonly, some case studies have followed aquaculture supply chains through processing, transportation, consumption and post-consumer activities. Feed production and farm electricity are commonly found to be the major drivers of GHGs in aquaculture systems. Application of LCA studies of different farming systems and sites will identify the practices with the least environmental impacts to make the shrimp industry more sustainable.

All stages in shrimp and fish aquaculture supply chain including reproductive behaviour, breeding and seed production in hatchery, and growth and behaviour of shrimp/fish in ponds are going to be largely affected by the climate change phenomena. To make aquaculture production sustainable and provide the animal protein continuously to the ever growing population of the country, aquaculture has the responsibility not only to evolve itself against the changing climate to remain productive on a sustainable basis, but also has to put simultaneous effort to mitigate the global emission of greenhouse gases.

Use of large quantity of manure, fertilizer, feed, therapeutics etc. aimed at increasing the shrimp production, has made the modern shrimp aqua farming

system more energy intensive. Carbon sources associated with aquaculture includes direct use of fossil fuels in production activities, indirect fossil fuel use, stock respiration and waste decomposition and sediment management. In this context, the vast coverage of aquaculture ponds in the country could be a significant source of greenhouse gases emission. However, responsible aquaculture practice can alter the trend by making aquaculture a pro-carbon sink process rather than contributing to the global greenhouse gas emission. It is important to study all the processes involved in shrimp/fish production from cradle to grave which can enable us to intervene to make aquaculture eco-friendly. There is a need to identify the processes and materials within the aquaculture production sector that are contributing maximum to the global warming potential, identify hotspots in the whole supply chain including transportation and energy use that are responsible for global warming potential and plan alternate scenarios to mitigate climate change impacts.

Concept of life cycle assessment

Life cycle assessment (LCA) is an upcoming international standardized method (ISO 2006) aimed at learning knowledge and skills to analyze the various processes involved in the shrimp/fish production chain and find out their impact on the environment and climate change. The LCA also known as life cycle analysis, is a structured, comprehensive and internationally standardized method used to evaluate the global impact of the various products, production systems and the different processes involved in it on the environment. Life cycle thinking (LCT) and LCA are the scientific approaches behind modern environmental policies and business decision support related to Sustainable Consumption and Production (SCP). The LCA study quantifies all relevant emissions and resources consumed and the related environmental and health impacts and resource depletion issues that are associated with any goods or services ("products"). It takes into account a product's full life cycle to perform a function from the extraction of resources, through production, use, and recycling up to the disposal of remaining waste (cradle to grave) (Fig. 1). It is a vital and powerful decision support tool, complementing other methods, which are equally necessary to help effectively and efficiently make consumption and production more sustainable. The LCA is performed in iterative loops of goal and scope definition, inventory data collection and modeling (LCI), impact assessment (LCIA), and with completeness, sensitivity and consistency checks (evaluation) as a steering instrument.
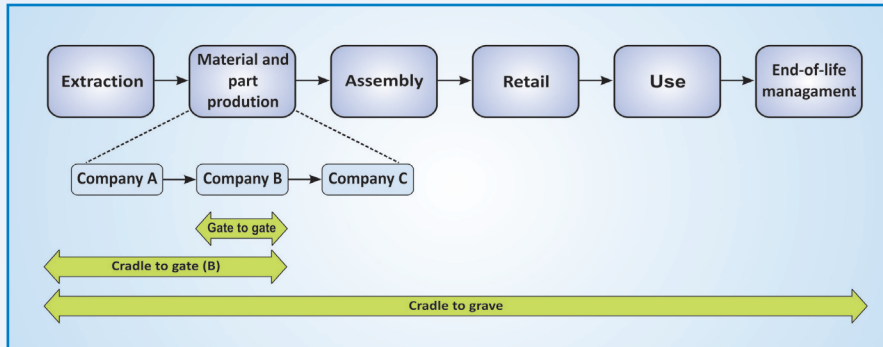
Fig. 1. Different stages (Cradle to grave, cradle to gate and gate to gate) in life cycle assessment process (*Source:* EU 2010)

Some people find the LCA useful as a conceptual framework, while others see it as a set of practical tools. However, both views are correct, depending on the context. Generally, this method relies on gathering information on all phases of the 'Life cycle' of product including raw material use, energy of productions, manufacturing and transport. It envisages analyzing contribution of a product (production processes) towards global warming potential (GWP), eutrophication, acidification, ozone layer depletion, ecotoxicity (freshwater and marine), etc. on a global as well as regional basis. Such methodology can be effectively utilized in identifying the potential hot spots in a production process so that modified or alternative methods or processes can be evolved which can replace those hot spots so as to mitigate the potential impact.

LCA framework and methodology

The methodology in the LCA comprises four major steps. a) Goal and scope definition, b) Life cycle inventory (LCI) analysis, c) Impact assessment, d) Interpretation of the results (Fig. 2).
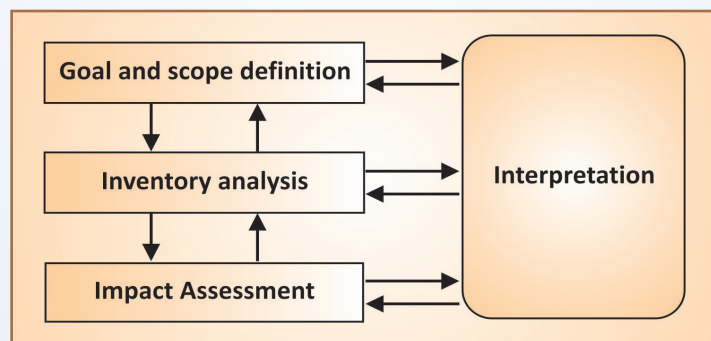

Fig. 2. The LCA framework and methodology

a) Goal and scope definition

The goal and scope definition of the LCA study involves selection of a product system and defining the functional units, boundaries, allocation methods, and impact categories of the production system. This phase attempts to set the extent of the inquiry as well as specify the methods used to conduct it. It involves stating and justifying the goal of the LCA study, explaining the goal (aim or objective) of the study and specifying the intended use of the result (application), the initiator (and commissioner) of the study, the practitioner, the stake holders and the intended user of the study result (target audience).

Functional unit

The functional unit (FU) describes the primary function(s) of a (product) system, and indicates how much of this function is to be considered in the intended LCA study. For example: if we intend to compare an improve extensive P. monodon culture system and intensive L. vannamei culture system, then production of one ton shrimp biomass may be considered as the FU and contribution of the processes for producing this one ton shrimp in both cases may be compared. It forms the basis of all calculations and for the comparisons of alternative product systems. The functional unit enables different systems to be treated as functionally equivalent and allows reference flows to be determined for each of them. The reference flow is the measure of the output from the processes in a given product system which are required to fulfill the function expressed by the functional unit. On the basis of functional unit, a number of alternative product systems can be declared as functionally equivalent and reference flow will be determined for these systems.

The results of the goal and scope definition phase gives a clear goal of the study, well defined functional unit and the reference flow for various alternative product system. All these form the input for the next stage of the LCA study i.e., inventory analysis.

b) Life cycle inventory (LCI) analysis

The inventory analysis is the phase in which the product system (systems if there is more than one alternative) is defined. The different steps involved in this processes includes i) setting the system boundaries (between economy and environment with other product system and in relation to cut-off, ii) designing the flow diagram with unit processes, iii) collecting the data for each of these processes, iv) performing allocation for multifunctional processes, and v) completing the final calculation.

The main result comes in the form of an inventory table listing the quantified input from and output to the environment associated with the functional unit in terms of kg of CO_2, mg of phenol and cubic meter of natural gas.

i) System boundary

In LCA, each and every flow should be followed until its economic input and output have been translated into environmental intervention, i.e flows of the natural resources into the product system without prior humane transformation or the flow of the materials leaving the product system which are discarded to the environment without subsequent humane transformation. Every product system is a collection of materially and energetically connected unit processes which performs one or more defined functions. For example: in the fish meal production process fishing, transport and treatment of the fish at factory are the few unit processes.

While performing a life cycle assessment data are collected for each smallest portion of a product system, i.e. unit process. Since it is not possible to include all the unit processes into the study of a product system, there is a necessity to define the system boundary. The 'System boundary' defines the unit processes to be included in the system to be modeled. For example: Fish meal production may be included in the system boundary of shrimp production as it is a considerable part while post larvae production may be avoided as it is insignificant for unit production of shrimp. Fig. 3 depicts the system boundaries for production process in shrimp aquaculture supply chain.
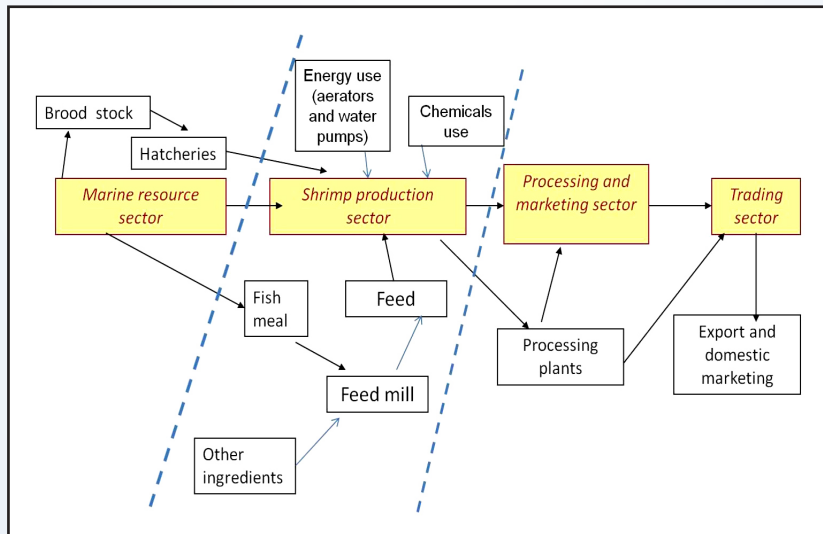

Fig. 3. System boundary for LCA of grow-out production in shrimp aquaculture supply chain

Three boundary issues in LCA

a) Boundary between the product system and the environment affected

b) Boundary between the processes that are relevant and irrelevant to the product system [cut off] {e.g. in production of 1.0 t shrimp, impact of the process contributing required post larvae is negligible and hence may be avoided, while the process involved to produce 1.5 t feed (used for the production of 1 ton shrimp) should be considered relevant because of the quantity}

c) Boundary between the product system under consideration and other product system [allocation] (to produce rice bran, paddy crop has to be raised. Since rice is the main produce in rice processing process and rice bran is the co-product, allocation is made, mostly on the basis on economic value).

ii) Designing the flow diagram with unit processes

The flow diagram provides an outline of the major unit processes within a production system including their inter-relation. It starts with preparation of the initial flow diagram for each alternative product system studied at the level of aggregated processes for each life cycle stage. It starts from the reference flow, the process producing the reference flow and the adjacent processes including the processes producing the main materials and those managing the main waste flows. This is followed by detailed diagrams, at the level of unit processes in iteration with the data collection step.

Data collection is the most demanding task in an LCA and is determined by goal and scope. The data collection phase primarily involves collection of the relevant data on the unit processes and quantifying all flows connected to the unit processes. In most of the existing LCA Data base, the process data are always almost quantified in relation to some physical (reference) flow (1 kg of material or I MJ of energy). During data collection one may find a need to review the goal and scope again and again (iteration) due to some technical problems such as i) sometimes initial decisions are not practical (data not available), ii) Important choices forgotten, iii) Too ambitious for the time and budget. The data should be relevant (represents what it is supposed to represent), reliable (based on precision and uncertainty) and reproducible (documented transparently). It is to be checked whether the data is the average of few data or generated from a single producer.

The collected data are classified as the foreground and background data. The foreground data (primary data collected on site) refers to processes that are of specific interest for the current LCA, like production processes while

the background data (secondary data collected from generic sources) refers to processes that support the foreground data, like electricity, transport processes, waste treatment, auxiliary materials etc. The decision is made on the system boundary for the production system depending on the relevance of contribution of a unit process for the production of functional unit and only those material and energy inputs and waste and emission outputs of all economic processes that are within the system boundaries are considered. Inventory table for each unit processes within the system boundary are prepared followed by preparation of aggregate inventory table for reference flow.

iii) Data validation

Validity of the process data is done in this step, for which various tools are available including the mass balance, energy balance and comparison with data from other sources. Inadequate data and missing data are taken care of and decision is taken how to fill the gap.

iv) Allocation

The problem of how to divide emissions and material consumption between several product or processes is called allocation. Generally multi-output and multi-input processes require allocation. Due to the multifunctional nature of the product processes having more than one product and use of raw material input often including intermediate and discarded products, it becomes critical to make decision about which of the economic flow and environmental intervention are to be allocated to the functional unit produced by the system. Co-production, waste treatment, recycling and reuse are 3 types of processes where allocation is necessary. For example: wheat flour is used as the feed ingredients in shrimp feed manufacture. The wheat bran is a co-product and to get it, wheat has to be produced. Then the problem comes in determining what portion of the impact of wheat production should be allocated to the production of the wheat flour.

Generally allocation of the environmental burden of the co-products is avoided in LCA study using single function as the basis. However, in cases where allocation cannot be avoided, the allocation of the environmental burden should be done based on the underlying physical relationship or in other case it is done based on economic value. The reason for the allocation should be properly mentioned. Hierarchy of preferred allocation approaches as per ISO 14044 is given below.

- Avoiding allocation by dividing the unit process
- Avoiding allocation by system expansion

- Allocation on the basis of mass relationship

- Allocation on the basis of economic relationship

v) Negligible contribution (cutoff) criteria

This is a process in which the unit processes whose contribution to the production of the functional unit is negligible or insignificant are not considered for life cycle assessment study.

c) Impact assessment

The results of the inventory process, i.e. the inventory table are further processed and interpreted in terms of potential impacts associated with the identified forms of resource use and environmental emissions. The impact categories are decided to assess the impact (Fig. 4). Some of the impact category includes potentials of global warming, eutrophication, acidification, human toxicity, ozone layer depletion, freshwater toxicity, marine toxicity etc. The important impact categories for aquaculture production systems are global warming, eutrophication and acidification (Table 1). The interventions recorded in the inventory table are quantified in terms of common category indicator. Characterization models are used for this from which characterization factors are derived for individual pollutants. The main results of this phase forms the input for interpretation phase and includes environmental profile, the normalized environmental profile and the weighting profile. The LCI results are characterised to produce a number of impact category indicators. The environmental relevance of each indicator has to be documented by describing the link to the endpoints. The LCAs are performed in iterative loops of goal and scope definition, inventory data collection and modeling (LCI), impact assessment (LCIA), and with completeness, sensitivity and consistency checks (Evaluation) as a steering instrument. Revision of the goal and scope should be done until the required accuracy of the system's model and processes and the required completeness and precision.

Table 1. Important impact categories for aquaculture production systems.

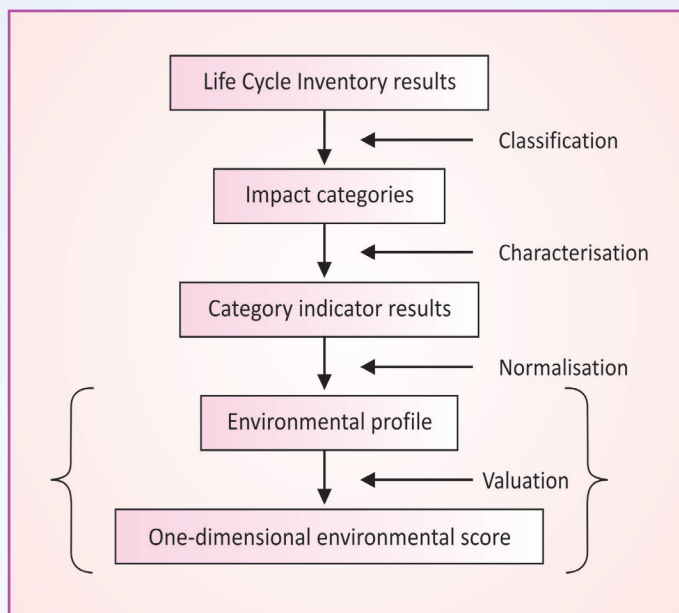| Impact category	Damage	Contributing substances
Global warming	Increase of radiative forcing	CO_2, CH_4, N_2O, CFCs
Acidification	Release of hydrogen ions	SOx, NOx, HCl
Eutrophication	Increased growth of aquatic biomass	N, P, organic matter

Fig. 4. Impact assesment process in the life cycle analysis

d) Interpretation of the results

In this phase, result of the analysis and all assumptions made during the course of analysis are evaluated in terms of soundness and robustness and overall conclusions are drawn. The main elements of the interpretation phase are an evaluation of the result (in terms of consistency and completeness), an analysis of result, formulation and recommendation of the study. Such consistency, completeness and robustness are checked following appropriate methodology. The results of the interpretation phase are twofold. First, there are results of all forms of consistency and uncertainty analysis, leading to a number of judgments related to the quality and robustness of the findings of the inventory analysis and impact assessment. Secondly, there is a description of the final conclusion and recommendation as to product choice or process improvement.

Flow diagrams and preparation of questionnaire

Questionnaires have to be developed for collecting data on production systems in aquaculture including whole supply chain. Further, the questionnaires are to be tested and modified after group discussions with the researchers working on LCA. Flow diagrams for production systems are to be prepared and system boundaries have to be decided. The detailed flow diagram of shrimp production system is

depicted in Fig. 5. The unit processes considered for the actual production are kept within the large rectangle while other unit processes are kept out side. Some of the unit processes like seed production are also considered as cut off because of their negligible contribution towards production of the functional unit (i.e., 1 ton production). The comparison was made solely for the practice purpose and does not represent true situation and presented here only an example of how to interpret the results.
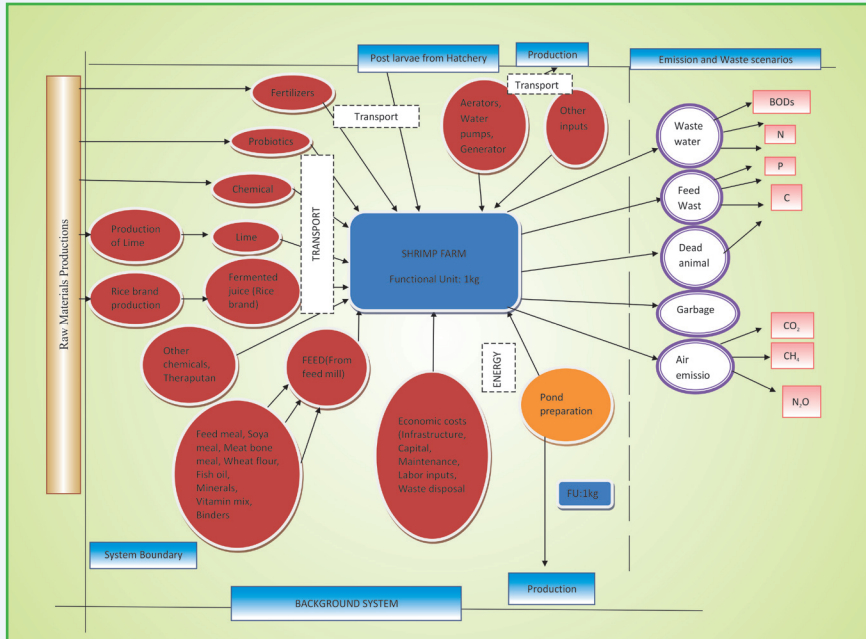
Fig. 5. Detailed flow diagram of the shrimp production process for life cycle analysis

Use of LCA software for data analysis

The SIMAPRO software is specifically designed for the LCA study and simultaneously learnt to handle the database. The SIMAPRO Software has important contributions to the LCA methodology since 1990 and is the world's most widely used LCA software. Approximately 10,000 processes are available in the software with multiple impact assessment methods such as Eco-indicator 95/99, CML2 Baseline 2000. It has unique features of databases, libraries, processes and product stages. It also has provisions for programming, managing of data, storing of data, making calculations and to check the reliability. This gave the idea about the type of data required to be collected to conduct the LCA study.

The collected data has to be analysed with the 'SIMAPRO' software to identify the hot spots and to understand their contribution towards global warming and climate change processes. Comparisons can be drawn on the impacts between the different production systems and with different production levels within the same production system (for example, in shrimp two production systems, P. monodon and L. vannamei and in each production system at different levels of production). Many times during the analysis, based on the outcome of the analysed data further modifications have to be made in the questionnaire meant for the LCA study.

The impact categories quantification output based on the characterisation and normalisation values is in terms of graphical representation as per cent contribution from each process to the impact category and the normalised values to the total. The contribution from each phase of the production process to the total is also quantified. The analysis also displays the network which shows the contribution from each input (materials) and also the processes contributing to global warming potential.

Limitations in the LCA

The LCA cannot or at least should not be used to claim that a particular product is environmentally friendly. At best it is only possible to say, using a specified set of criteria, that one product is better than another in certain aspects of its performance. Comparison studies based on selected indicators or impact categories (e.g. Carbon footprint based comparisons) shall highlight that the comparison is not suitable to identify environmental preferable alternatives, as it only covers the considered impact(s) (e.g. Climate change). A life cycle study with a strong focus on sustainability would find the lack of integration between life cycle costing and social life cycle assessment problematic.

Conclusion

The LCA as a decision support tool used in the right way, can help to ensure environmental soundness, whether in the design, manufacture or use of a product or system. On the financial side, companies using the LCA can discover important product improvements, new approaches to process optimization and even, in some cases, radically new ways of meeting the same need, but with a new product, or with a service. Eco-labelling of products has proceeded less fast in many countries, but where it has been used, there has been an almost automatic requirement for LCA inputs. Finally, alternate scenarios can be made for the processes contributing more towards global warming potential.

References

EU (2010) International Reference Life Cycle Data System ILCD Handbook: General guide for Life Cycle Assessment - Detailed guidance, European Commission, Joint Research Centre Institute for Environment and Sustainability, European Union, 414 p.

ISO (2006) Report of the International Organization for Standardization 14040:2006 (E) Environmental Management – Life Cycle Assessment – Principles and Framework, p. 1-20.

Pelletier N and Tyedmers P (2008) Life cycle considerations for improving sustainability assessments in seafood awareness campaigns. Environment Manage 42: 918-931.

Thrane M, Ziegler F and Sonesson U (2009) Eco-labelling of wild-caught seafood products. J Cleaner Production 17: 416-423.

Greenhouse Gas Emissions Inventory

Chapter 9

Inventory for Greenhouse Gas Emissions from Crop Production Sector

A Bhatia, N Jain and H Pathak

Global atmospheric concentrations of methane (CH_4) (1774 ppb) and nitrous oxide (N_2O) (319 ppb) have increased markedly as a result of human activities. The observed increase in CH_4 and N_2O concentration is predominantly due to agriculture and fossil fuel use. Globally, agriculture accounts for about 60% of nitrous oxide (N_2O) and 50% of methane (CH_4) emission. Agricultural CH_4 and N_2O emissions increased by 17% from 1990 to 2005 (Smith 2007). Soil emissions (38% of CH_4 + N_2O), rice production (11% of CH_4) and biomass burning (12% of CH_4 + N_2O) are the three major sources of global methane and nitrous oxide emissions from the agriculture sector.

Inventory of methane emission from rice fields

Anaerobic conditions in wetland rice fields as a result of soil submergence are one of the most important sources of CH_4 emission. Decomposition of organic material in flooded rice fields produces methane (CH_4), which escapes to the atmosphere primarily by vascular transport through the rice plants. The annual amount of CH_4 emitted from a given area of rice is a function of the crop duration, water regimes and organic soil amendments. The CH_4 emissions are estimated by multiplying the seasonal emission factors by the annual harvested areas. Harvested area for each sub-unit (state) will be multiplied by the respective emission factor that is representative of the conditions that define the sub-unit (state). The total annual emissions are equal to the sum of emissions from each sub-unit of harvested area using the following equation.

$$CH_{4\,Rice} = \Sigma_{i,j,k} (EF_{i,j,k} \bullet A_{i,j,k} \bullet 10^{-6}) \qquad (1)$$

Where $CH_{4\,Rice}$ = annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}; EF_{ijk} = a seasonal integrated emission factor for i, j, and k conditions, kg CH_4 ha^{-1}; A_{ijk} = 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, under which CH_4 emissions from rice may vary. Separate calculations were undertaken for each rice ecosystems (i.e., irrigated, rainfed and deep water rice production).

The baseline emission factor is scaled for organic amendments and water regime in rice ecosystems according to the equation (2) given below

$$EFi = EFc \bullet SFw \bullet SFp \bullet SFo \qquad (2)$$

EFi = adjusted seasonal emission factor for a particular harvested area (state)

EFc = baseline emission factor for continuously flooded fields without organic amendments. A baseline emission factor for no flooded fields for less than 180 days prior to rice cultivation and continuously flooded during the rice cultivation period without organic amendments (EFc) is used as a starting point. The IPCC default for EFc is 1.30 kg CH_4 ha^{-1} day^{-1} (with error range of 0.80 - 2.20).

SFw = scaling factor to account for the differences in water regime during the cultivation period.

SFp = scaling factor to account for the differences in water regime in the pre-season before the cultivation period

SFo = scaling factor for both type and amount of organic amendment applied. (More CH_4 is emitted from amendments containing higher amounts of easily decomposable carbon and emissions also increase as more of each organic amendment is applied. The scaling factor should be based on the application rate of organic amendment and also its conversion factor.)

Uncertainties in methane emission

The uncertainties associated with estimation of CH_4 emission are quite significant. Uncertainties arise due to differing conditions such as climate, agronomic practices, and soil properties. Various physical, chemical and biological properties of soil influence formation of CH_4 in soil. Uncertainties in emission factors primarily arise due to different soil types, rice cultivars used and also the different agronomic practices of water, fertilizer and manure management. There is uncertainty associated in the duration of different rice varieties used in a state. The most popular cultivar of a region will have to be identified based on area under its cultivation and also on expert judgment. Maximum uncertainty will be associated with this factor.

Timing of organic amendment application especially rice straw incorporation may lead to uncertainty. Uncertainties arise due to non availability of harvested area under each water regime and type of organic amendment in a particular rice ecosystem. Most likely, activity data will be more reliable as compared to the accuracy of the emission factors.

Inventory of nitrous oxide emissions from managed soils

Nitrous oxide is produced naturally in soils through the processes of nitrification and denitrification. Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas (N_2). Nitrous oxide is a gaseous intermediate in the reaction sequence of denitrification and a by-product of nitrification that leaks from microbial cells into the soil and ultimately into the atmosphere. One of the main controlling factors in this reaction is the availability of inorganic N in the soil. This methodology, therefore, estimates N_2O emissions using human-induced net N additions to soils (e.g., synthetic or organic fertilizers, deposited manure, crop residues, sewage sludge), or of mineralization of N in soil organic matter following drainage/management of organic soils, or cultivation/land-use change on mineral soils.

The emissions of N_2O that result from anthropogenic N inputs or N mineralization occur through both a direct pathway (i.e., directly from the soils to which the N is added/released), and through two indirect pathways: (i) following volatilization of NH_3 and NOx from managed soils and from fossil fuel combustion and biomass burning, and the subsequent redeposition of these gases and their products NH_4^+ and NO_3^- to soils and waters; and (ii) after leaching and runoff of N, mainly as NO_3^-, from managed soils.

Total emissions of N_2O from managed soils are estimated using equation (3).

Total N_2O- N emission:

$$N_2O\text{-}N_{\text{TOTAL}} = N_2O\text{-}N_{\text{DIRECT}} + N_2O\text{-}N_{\text{INDIRECT}} \qquad (3)$$

Direct emissions of N_2O from managed soils are estimated separately from indirect emissions, though using a common set of activity data.

In most soils, an increase in available N enhances nitrification and denitrification rates which then increase the production of N_2O. Increases in available N can occur through human-induced N additions or change of land-use and/or management practices that mineralize soil organic N.

The following N sources will be included in the methodology for estimating direct and indirect N_2O emissions from managed soils:

- Synthetic N fertilizers (F_{SN})
- Organic N applied as fertilizer (e.g., animal manure, compost, sewage sludge) (F_{ON})
- Urine and dung N deposited as manure (F_{PRP})
- N in crop residues (above-ground and below-ground), including from N-fixing (F_{CR})
- N mineralization associated with loss of soil organic matter resulting from management of mineral soils (F_{SOM})
- Drainage/management of organic soils (i.e., Histosols) (F_{OS}).

Direct N_2O emission

The following equation is used for estimating direct N_2O emissions from managed soils:

$$N_2O_{Direct} - N = N_2O - N_{N\ inputs} + N_2O - N_{OS} + N_2O - N_{CAS} \tag{4}$$

Where:

$$N_2O - N_{N\ inputs} = \{([F_{SN} + F_{ON} + F_{CR} + F_{SOM}] * EF_1)$$

$$+$$

$$([F_{SN} + F_{ON} + F_{CR} + F_{SOM}]_{FR} * EF_{1FR})\}$$

$$N_2O - N_{OS} = ([F_{OS,CG,Temp} * EF_{2\ CG,\ Temp}] + [F_{OS,CG,Trop} * EF_{2\ CG,\ Trop}])$$

$$N_2O - N_{CAS} = [F_{AS,C} * EF_{3\ AS,C}]$$

Where:

N_2O Direct –N = annual direct N_2O–N emissions produced from managed soils, kg N_2O–N yr^{-1}

N_2O–$N_{N\ inputs}$ = annual direct N_2O–N emissions from N inputs to managed soils, kg N_2O–N yr^{-1}

N_2O–N_{OS} = annual direct N_2O–N emissions from managed organic soils, kg N_2O–N yr^{-1}

N_2O–N_{CAS} = annual direct N_2O–N emissions from urine and dung inputs by cattle to agricultural soils, kg N_2O–N yr^{-1}

F_{SN} = annual amount of synthetic fertilizer N applied to soils, kg N yr^{-1}

F_{ON} = annual amount of animal manure, compost, and other organic N additions applied to soils (Note: N_2O emissions from the N in sewage sludge are accounted for in waste sector), kg N yr^{-1}

F_{CR} = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, returned to soils, kg N yr^{-1}

F_{SOM} = annual amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg Nyr^{-1}

F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts CG, Trop refer to Cropland and Tropical respectively)

F_{CAS} = annual amount of urine and dung N deposited by animals (cattle) when performing jobs on agricultural soils kg N yr^{-1} (Note: the subscripts C refer to Cattle)

EF_1 = emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)$^{-1}$

EF_{1FR} is the emission factor for N_2O emissions from N inputs to flooded rice, kg N_2O–N (kg N input)$^{-1}$

EF_2 = emission factor for N_2O emissions from drained/managed organic soils, kg N_2O–N ha^{-1} yr^{-1}

EF_{3CAS} = emission factor for N_2O emissions from urine and dung N deposited on agricultural soils by animals (cattle used for agricultural jobs), kg N_2O–N (kg N input)$^{-1}$

Activity Data

Applied synthetic N fertiliser (F_{SN})

The term F_{SN} refers to the annual amount of synthetic N fertiliser applied to soils. It is estimated from the total amount of synthetic fertiliser consumed annually. Annual fertiliser consumption data may be collected from Fertilizer statistics.

Applied organic N fertiliser (F_{ON})

The applied organic N fertiliser (F_{ON}) refers to the amount of organic N inputs applied to soils other than by grazing animals and is calculated using Equation 5. This includes applied manure and compost applied to soils. Sewage sludge is generally accounted for in the waste sector.

$$F_{ON} = F_{AM} + F_{COMP} + F_{GM} \qquad (5)$$

Where:

F_{ON} = total annual amount of organic N fertiliser applied to soils other than by grazing animals, kg N yr^{-1}

F_{AM} = annual amount of animal manure N applied to soils, kg N yr^{-1}

F_{COMP} = annual amount of total compost N applied to soils, kg N yr^{-1}

F_{GM} is the amount of green manure nitrogen, Kg N yr^{-1} applied to soils annually. (Addition of N through green manure crops (N_{GM}) such as sesbania (Sesbania aculeata) and sun hemp (Crotalaria juncea) etc is included here).

The term F_{AM} is determined by adjusting the amount of manure N available (calculated from livestock population) for the amount of managed manure used for feed ($Frac_{FEED}$), burned for fuel ($Frac_{FUEL}$), or used for construction ($Frac_{CNST}$) as shown in Equation (6). Categories of livestock include cattle, buffalo, sheep, goat, camel and poultry.

$$F_{AM} = N_{MMS\ Avb} \bullet (1 - Frac_{FEED} + Frac_{FUEL} + Frac_{CNST} + Frac_{COLLEC}) \qquad (6)$$

Where:

F_{AM} = annual amount of animal manure N applied to soils, kg N yr^{-1}

N_{MMS_Avb} = amount of managed manure N available for soil application, feed, fuel or construction, kg N yr^{-1}

$Frac_{FEED}$ = fraction of managed manure used for feed

$Frac_{FUEL}$ = fraction of managed manure used for fuel

$Frac_{CNST}$ = fraction of managed manure used for construction

$Frac_{COLLEC}$ is the fraction of managed manure lost during collection of dung

Urine and dung from grazing animals (F_{PRP})

This is estimated using Equation (7) from the number of cattle $N_{(C)}$ that is used on agricultural soils, the annual average amount of N excreted by cattle $N_{ex(C)}$, and the fraction of this N deposited on soils $MS_{(C)}$.

$$F_{PRP} = [N_{(C)} * Nex_{(C)}) * MS_{(C)}] \qquad (7)$$

Where:

F_{PRP} = annual amount of urine and dung N deposited by cattle, kg N yr^{-1}

$N_{(C)}$ = number of cattle used for agricultural jobs in the country

$N_{ex(C)}$ = annual average N excretion per head of cattle used for agricultural jobs in the country, kg N animal^{-1} yr^{-1}

$MS_{(C)}$ = fraction of total annual N excretion for cattle that is deposited while performing agricultural jobs

Crop residue N, including N-fixing crops and forage, returned to soils (FCR)

The term FCR refers to the amount of N in crop residues (above-ground and below-ground), including N-fixing crops, returned to soils annually (Eq. 8.).

$$F_{CR} = \Sigma_T \{ Crop_{(T)} * (Area_{(T)} - Area\ burnt_{(T)} * C_f) * Frac_{Renew\ (T)} * \qquad (8)$$
$$[R_{AG(T)} * N_{AG(T)} * (1- Frac_{Remove(T)}) + R_{BG(T)} * N_{BG(T)}] \}$$

Where:

F_{CR} = annual amount of N in crop residues (above and below ground), including N-fixing crops, returned to soils annually, kg N yr^{-1}

$Crop_{(T)}$ = harvested annual dry matter yield for crop T, kg d.m. ha^{-1}

$Area_{(T)}$ = total annual area harvested of crop T, ha yr^{-1}

$Area\ burnt_{(T)}$ = annual area of crop T burnt, ha yr^{-1}

C_f = combustion factor (dimensionless)

$Frac_{Renew\ (T)}$ = fraction of total area under crop T that is renewed annually. For annual crops $Frac_{Renew}$ = 1

$R_{AG(T)}$ = ratio of above-ground residues dry matter (AGDM(T)) to harvested yield for crop T (Crop(T)), kg dm (kg dm)$^{-1}$

$= AG_{DM(T)} \times 1000 / Crop_{(T)}$

$N_{AG(T)}$ = N content of above-ground residues for crop T, kg N (kg dm)$^{-1}$

$Frac_{Remove(T)}$ = fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding and construction, kg N (kg crop-N)$^{-1}$

$R_{BG(T)}$ = ratio of below-ground residues to harvested yield for crop T, kg dm (kg dm)$^{-1}$

$N_{BG(T)}$ = N content of below-ground residues for crop T, kg N (kg dm)$^{-1}$

T = crop type

$Frac_{NCRST}$ is the nitrogen content of residue of different crops. Major non N fixing crops and N-fixing crops such as tur, gram, groundnut soybean, and other rabi and kharif pulses, may be taken for the calculation.

Mineralized N resulting from loss of soil organic C stocks in mineral soils through land-use change or management practices (F_{SOM})

The term F_{SOM} refers to the amount of N mineralized from loss in soil organic C in mineral soils through land use change or management practices. Where a loss of soil C occurs, this loss will be accompanied by a simultaneous mineralization of N. This mineralized N is regarded as an additional source of N available for conversion to N_2O just as mineral N released from decomposition of crop residues, for example, becomes a source.

The same default emission factor (EF1) is applied to mineralized N from soil organic matter loss as is used for direct emissions resulting from fertiliser and organic N inputs to agricultural land. This is because the ammonium and nitrate resulting from soil organic matter mineralization is of equal value as a substrate for the microorganisms producing N_2O by nitrification and denitrification, no matter whether the mineral N source is soil organic matter loss from land-use or management change, decomposition of crop residues, synthetic fertilizers or organic amendments.

$$F_{SOM} = \Sigma_{LU} \left[(\Delta C_{MINERAL, LU} * 1/R) * 1000 \right] \qquad (9)$$

F_{SOM} = the net annual amount of N mineralized in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral, LU}$ = average annual loss of soil carbon for each land-use type (LU), tons C.

R = C:N ratio of the soil organic matter.

The amount of N mineralized can be calculated from the decomposition of soil organic carbon (SOC).

Nitrous oxide emission (N_2O-N ha^{-1}) due to mineralization of organic N from soil into inorganic pool (NH_4^+) may be calculated in relation to mineralization of C using the following equation (Pathak and Wassmann 2007).

$$N_2O\text{-N} = SOC \times 1000 \times 45 \times BD \times 0.000085 / 10 \times 365 \times 0.0024 \qquad (10)$$

Where, SOC is soil organic C (%), 1000 and 45 are the coefficients used to calculate the weight of soil up to 45 cm depth, BD is soil bulk density (Mg m^{-3}), 10 is the C:N ratio of soil organic matter, 0.000085 is rate of mineralization (Seligman and van Keulen 1981), 365 is duration (days) and 0.0024 is rates of nitrification and denitrification (kg kg^{-1}). A similar approach has been used in the denitrification and decomposition (DNDC) model for estimating N_2O emission from soil (Li 2000).

Area of drained/managed organic soils (FOS)

The term FOS refers to the total annual area (ha) of drained/managed organic soils. FOS is the area of organic soils harvested (area of organic soils cultivated annually). Organic soils are those, which contain more than 12-18% of organic carbon depending upon the clay content. Indian soils are deficient of organic carbon, which is less than 1%. Only some cultivated soils of Kerala and northeast hill regions contain higher organic carbon (about 5%)

Emission factor for nitrous oxide emissions

The EF_1 is the emission factor for N_2O-N emitted from the various nitrogen additions to the soil. According to IPCC (2006) EF_1 has a default value of 1%. EF_1 based on the studies conducted in India (Pathak et al. 2002, Ghosh et al. 2002, Bhatia et al. 2005) has been calculated as 0.7%.

Indirect N_2O Emission

Emissions of N_2O also take place through two indirect pathways of volatilization and leaching (mentioned above).

$$N_2O_{indirect} = N_2O_{(ATD)} + N_2O_{(L)}$$

Where, $N_2O_{indirect}$ denotes the emission of N_2O-N indirectly from agriculture.

Volatilization $N_2O_{(ATD)}$

The N_2O emissions from atmospheric deposition of N volatilized from managed soil are estimated using Eq. 11.

$$N_2O_{(ATD)}\text{-}N = [(F_{SN} \bullet Frac_{GASF}) + ((F_{ON} + F_{PRP}) \bullet Frac_{GASM})] \bullet EF_3 \tag{11}$$

Where, $N_2O_{(ATD)}$-N = annual amount of N_2O–N produced from atmospheric deposition of N volatilized from managed soils, kg N_2O–N yr^{-1}; F_{SN} = annual amount of synthetic fertilizer N applied to soils, kg N yr-1; FracGASF = fraction of synthetic fertilizer N that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied)$^{-1}$. $Frac_{GASF}$ is the fraction of fertilizer that volatilizes as NH_3 and NO_x. Extents of volatilization, however, depend on several of soil, management, plant and climatic factors like the amount of N applied, soil pH, temperature and moisture.

F_{ON} = annual amount of managed animal manure, compost, other organic N additions applied to soils, kg N yr^{-1}

F_{PRP} = annual amount of dung N deposited by animals during grazing, kg N yr^{-1}

$Frac_{GASM}$ = fraction of applied organic N fertilizer materials (F_{ON}) and dung N deposited during grazing that volatilizes as NH_3 and NO_x, kg N volatilized (kg of N applied or deposited)$^{-1}$. $Frac_{GASM}$ is the fraction of N that volatilizes as NH_3 & NO_x, which is 15% of the N content of manure

EF_3 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N_2O (kg NH_3–N + NOx–N volatilized)$^{-1}$]

$Frac_{GASF}$ is the fraction of fertilizer that volatilizes as NH_3 and NO_x

$\Sigma_T(N_{(T)} * Nex_{(T)}$ denotes the amount of animal manure nitrogen excreted annually. $Frac_{GASM}$ is the fraction of manure that volatilizes as NH_3 & NO_x. EF_3 is the emission factor for N_2O emissions from atmospheric NH_3 and NO_x, which is 1% as per IPCC (2006) default value.

Leaching/Runoff, N_2O (L)

The N_2O emissions from leaching and runoff in regions where leaching and runoff occurs are estimated using Equation 11:

$$N_2O_{(L)}\text{-}N = F_{SN} + F_{ON} + F_C + F_{CR} + F_{SOM} \bullet Frac_{LEACH\text{ -}(H)} \bullet EF_5 \tag{12}$$

Where:

$N_2O_{(L)}$–N = annual amount of N_2O–N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, kg N_2O–N yr^{-1}

F_{SN} = annual amount of synthetic fertilizer N applied to soils in regions where leaching/runoff occurs, kg N yr^{-1}

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs, kg N yr^{-1}

F_C = annual amount of urine and dung N deposited by cattle performing agricultural jobs in regions where leaching/runoff occurs, kg N yr^{-1}

F_{CR} = amount of N in crop residues (above- and below-ground), including N-fixing crops, returned to soils annually in regions where leaching/runoff occurs, kg N yr^{-1}

F_{SOM} = annual amount of N mineralized in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management in regions where leaching/runoff occurs, kg N yr^{-1}

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralized in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, kg N (kg of N additions)$^{-1}$.

EF_5 = emission factor for N_2O emissions from N leaching and runoff, kg N_2O–N (kg N leached and runoff)$^{-1}$

Emission factors for volatilization and leaching

Indigenous values for emission factors associated with volatilized and re-deposited N (EF_4), and associated with N lost through leaching/runoff (EF_5) are used. Since data across the country is not available, expert judgment may be used for deriving the emission factors. Uncertainties in emission factors are likely to be more than in the case of activity data.

Uncertainties in nitrous oxide emissions

The uncertainties associated with estimation of N_2O emission are quite significant (IPCC 2006). Various physical, chemical and biological properties as well as crop management practices influence diffusion of N_2O from soil to air. Different agricultural management practices per se have different impact on N_2O emission. It is not possible to quantify N_2O emission easily at large scales. So generally

field level data are used to upscale to regional, national and global level using default emission factors, and the methodologies recommended by the IPCC. The method suggested by IPCC is very simple and does not take into account agro-climatic factors of different regions which generally influence emission of these gases. The up-scaling processes that depend highly on the models and database are responsible for about 63% uncertainties (Xuri 2003). Moreover, the timing and mode of fertilizer application have a strong influence on N_2O emission from soil. IPCC currently assume a N_2O emission factor of 1% of the N applied to soils or released through activities that result in mineralization of organic matter in mineral soils. The uncertainty range in this emission factor ranges from 0.003 - 0.03%.

Methodology for estimating non-CO_2 emissions from crop residue burning

Currently, wastes from nine crops viz., rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut, are subjected to burning. The amount of agricultural waste produced by a country depends on its crop management system. Non-CO_2 emissions from crop residue burning will be calculated using the equation given below.

$$L_{fire} = A \bullet M_B \bullet C_f \bullet G_{ef} \bullet 10^{-3}$$

Where:

L_{fire} = amount of non-CO_2 greenhouse gas emissions from fire, tons of each GHG e.g., CH_4, N_2O, etc.

A = area burnt, ha

M_B = mass of crop residue available for combustion, tons ha^{-1}

C_f = combustion factor, dimensionless (default values will be used)

G_{ef} = emission factor, g kg^{-1} dry matter burnt (default values will be used)

The combustion factor is a measure of the proportion of the fuel (crop residue in our case) that is actually combusted, which varies as a function of the size and architecture of the fuel load, the moisture content of the fuel and the type of fire (i.e., intensity and rate of spread which is markedly affected by climatic variability and regional differences. G_{ef} is the emission factor and it gives the amount of a particular greenhouse gas emitted per unit of dry matter combusted, which can vary as a function of the carbon content of the biomass and the completeness of combustion. For species with high N concentrations, NOx and N_2O emissions from

fire can vary as a function of the N content of the fuel.

Choice of Activity Data

Activity data includes estimates of land areas under the crop types for which agricultural residues are normally burnt. The amount of fuel available may be estimated from crop production statistics and the ratio of crop yield to the residue produced.

Choice of Emission Factors

Indigenously developed emission factors should be used. But in the absence of such data, the default emission coefficients based on emission factors given by Andreae and Merlet (2001) may be used.

Uncertainty in emission from crop residue burning

Estimates of the area planted under each crop type for which residues are normally burnt may be highly uncertain. In India, the primary end-uses of crop residue are as animal fodder, industrial and domestic fuel, thatching, packaging, bedding, construction of walls/fences, and as green-manure and compost. The amount left is what is available for field burning, and only a fraction of this amount is actually subject to burning. This fraction is, in fact, highly uncertain and varies with local and regional climate, season, livestock distribution, availability of fuel wood, availability of fodder, weed infestation etc. In India, about 60% of households depend on traditional sources of energy, like fuel wood, dung cake and crop residue for meeting their cooking and heating needs. High uncertainties are associated with this estimate as biomass activity data are based only on small surveys carried out at different points of time. More exhaustive surveys are required to establish the quantity of various types of biomass used in the country.

References

Andreae MO and Merlet P (2001) Emission of trace gases and aerosols from biomass burning, Global Biogeochem Cycl 15: 955-966.

Bhatia A, Pathak H, Jain N, Singh PK and Singh AK (2005) Global warming potential of manure amended soils under rice-wheat system in the Indo-Gangetic Plains. Atmos. Environ 39: 6976-6984.

Ghosh S, Majumdar D and Jain MC (2002) Nitrous oxide emission from kharif and rabi legumes grown on an alluvial soil. Biol. Fertil. Soils 35: 473-478.

IPCC (Intergovernmental Panel on Climate Change) (2006) Guidelines for National

Greenhouse Gas Inventories IGES, Japan (www.ipcc.ch).

Li C (2000) Modeling trace gas emissions from agricultural ecosystems. Nutrient Cycl. Agroecosys 58: 259–276.

Majumdar D, Kumar S, Pathak H, Jain MC and Kumar U (2000) Reducing nitrous oxide emission from an irrigated rice field of north India with nitrification inhibitors. Agric. Ecosys. Environ 81: 163-169.

Pathak H, Bhatia A, Prasad S, Jain MC, Kumar S, Singh S and Kumar U (2002) Emission of nitrous oxide from soil in rice-wheat systems of Indo-Gangetic Plains of India. J. Environ. Monitor. Assess 77(2):163-178.

Pathak H and Wassmann R (2007) Introducing greenhouse gas mitigation as a development objective in rice-based agriculture: I. Generation of Technical Coefficients. Agric. Syst 94: 807-825.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B and Sirotenko O (2007) Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (Eds), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and USA.

Xuri X, Wang M and Wang Y (2003) Using a modified DNDC model to estimate N2O fluxes from semi-arid grassland in China. Soil Biol Biochem 35: 615–620.

Chapter 10

Inventory for Greenhouse Gas Emissions from Livestock Sector

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In the absence of precise information on methane conversion factors for Indian livestock, an attempt was made to develop methane conversion factors (MCF) for different livestock and used them for calculating methane emissions as per the IPCC methodology.

Method used to measure methane conversion factors (MCF)

In order to refine the values of methane conversion rates, methane emission from cattle and buffaloes were monitored using open circuit system that consisted of a multistage centrifugal pump driven by an induction motor. In the open circuit system the flow rate of air was chosen so that the concentration of methane remains less than 0.2% in the air either distal to animal or in expired air. The air was also drawn through a facemask worn by animal while standing or through a closed chamber to check system of methane monitoring. The expired gas was also collected in Douglas bag and the volume measurements were made. A sample of expired air/exhausted air was dried out and passed through methane analyzer (Analytical Development Co., England), The values were averaged. The change in gas concentration in the airflow was measured during the day or any specific period in relation to time of feeding. The emission was calculated as the product of the flow rate, the time and the average concentration (Upadhyay et al. 2007 2008).

Methane emission factors (MEF)

Methane emission factor is the average emission of methane per animal annually expressed in kg (kg/animal/year) for individual animal category based on animal related factors like body weights and their energy requirements for activity/ production. The IPCC equations given below were used after incorporating

appropriate conversion factors (Ym) values and calculations based on measurements of methane conversion.

(1) Maintenance: NEm(MJ/day)=0.322 • (weight in kg) 0.75

(2) Feeding: NEactivity = Captivity • NEm

(3) Growth: NEg (MJ/day) = 4.18 • {(0.0635 • 478/

(C FSBW) 0.75 • (0.96 • SWG) 1.097}

(4) Weight Loss: NE mobilized lactating dairy cows (MJ/day)

= 19.7 MJ/kg • (weight loss in kg/day)

(5) Draft Power: NEw (MJ/day) = 0.10 • NEm • hours of work/ day

(6) Pregnancy: NE required (MJ/283-dayperiod) = 35 MJ/kg • calf birth weight (kg)

(7) Calf birth weight (kg) = 0.233 • (cow weight in kg)0.79

(8) Metabolizable Energy (ME) = 0.82 • Digestible Energy (DE)

(9) NE/DE = 1.123 - (4.092 • 10-3 • DE%) + (1.126 • 10-5 (DE%)2)-25.4DE%

(10) NEg/DE = 1.164 – (5.160 • 10-3 • DE%) + (1.308 • 10-5 • (DE%)2) – 37.4/DE%

(11) GE= [((NEm +NEmobilized +NEa +NEl +NEp)/ {NEma/DE})+ (NE/ {NEga/ DE})]/ (DE% / 100)

(12) Emission (kg/yr) = [Intake (MJ/day) • Ym • (365 days/yr)]/[55.65 MJ/kg of methane]

Where GE = gross energy (MJ/day), NEm=net energy required by the animal for maintenance (MJ/day), NEmobilized= net energy due toweight loss (mobilized) (MJ/day), NEa= net energy for animal activity (MJ/day), NEl=net energy for lactation (MJ/day) or net energy for work, NEp=net energy required for pregnancy (MJ/day), Nema/DE}= ratio of net energy available in a diet for maintenance to digestible energy consumed, Neg= net energy needed for growth (MJ/day), {NEga/DE}= ratio of net energy available for growth in a diet to digestible energy consumed, DE= digestible energy expressed as a percentage of gross energy (per cent)

The gross energy requirements of both cattle and buffaloes were calculated as per IPCC guidelines for different categories. The feeds and feeding materials used for livestock feeding in India are crop byproducts and crop residues, agricultural

and industrial by products, forest produce and waste materials (Ranjhan 1999). The digestibility of feeds and feeding stuffs like straws and coarse feeds that constitute the major bulk of the feed intake of large livestock in India have been considered.

Since, gross energy intake of animal is a vital component on which methane emission is based, we have sub-categorized livestock according to species, age group, feeding practices; stall fed or grazing at small areas or at large areas; production level and stage of production. Productive animals like lactating cattle or buffalo, working, breeding, growing require additional energy. The non-dairy animals, pregnant and working animals have been categorized keeping in view their body weights. The weight loss due to seasonal variations and work has also been considered and an average loss of 1-2 % of bodyweight has been taken for calculating weight loss for working cattle and buffaloes.

Livestock categorization

Livestock Population

The 17th Livestock census results of India reveal that total livestock population during 2003 was 485 million consisting of 160 million indigenous cattle, 24 million crossbred cattle, 97 million buffaloes, 0.065 million yaks, 0.278 million mithuns, 61million sheep, 124 million goats and 16.72 million animals horses, pigs, donkey and camels. The large ruminants, constituting of cattle and buffaloes contribute to milk production and draught power. Small ruminants viz. sheep and goats contribute significantly to meat, wool and leather.

Cattle and Buffaloes

As per IPCC guidelines, the country specific body weights of animals were determined and GE intake based on animal performance data was calculated. The energy requirements were calculated as per IPCC guidelines for different categories of animals under different feeding situations. The digestibility of feeds and feeding stuffs were considered. The livestock have been sub-categorized according to species, age group, feeding practices; stall fed or grazing at small areas or at large areas; production level and stage of production. Productive animals like lactating cattle or buffalo, working, breeding, growing require energy in addition to maintenance and due considerations have been given in calculations as per IPCC guidelines. The weight loss due to seasonal variations and work has also been considered and an average loss of 1-2 % of body weight has been taken for calculating weight loss for working cattle and buffaloes.

The body weights of working cattle and buffaloes have been sub categorized as per spatial distribution of bullocks based on body weight information on bullocks (Singh 1999). The body weights adopted in the present estimation are higher than the body weights used by earlier studies (Swamy and Sashirekha 2004) to reduce uncertainties and reliability of estimates. Better management practices and improved animal feeding has resulted into higher weight gain of animals. The guidelines of IPCC good practices are followed strictly to reduce uncertainty (IPCC 1996). The population of sheep and goats has not been sub categorized and IPCC tier I methodology has been followed to calculate methane emission by enteric fermentation and manure management. The average annual population of Camels, Pigs horses, and ponies etc has been reported without any sub classification and IPCC default factors have been used.

Methane emission factors (MEF)

Methane emission factor is the average emission of methane per animal annually expressed in kg (kg/animal/year) for individual animal category based on animal related factors like bodyweights and their energy requirements for activity/production (Table 1). The IPCC equations were used after incorporating appropriate conversion factors values and calculations based on measurements of methane conversion (Table 2).

Table 1. Factors considered for calculating methane emission factors (MEF) for cattle and buffalo

S. No.	Description	Milking Animals (Dairy)		
		Cattle		Buffalo
		Indigenous	Crossbred	
1.	Avg. adult weight (kg)	255	300	400
2.	Body wt. range	200-365	210-500	375-525
3.	Feed situation	Stall Fed/ Good Pasture	Stall Fed \ Good Pasture	Stall Fed/Good Pasture
4.	Milk (kg/Day)	1.90	6.0	3.6
5.	Fat content	4.2 (3.7-5.5)	3.2 (2.7-4.5)	7.0 (6-9)
6.	% Pregnant	45-50	45-50	45-50
7.	Digestibility of feeds	65 (53-78)	65 (54-80)	65 (51-76)

Table 2. Methane emission coefficients for Indian cattle and buffaloes

Category	Sub category	Methane conversion factor*	Methane emission factor#
Dairy cattle	Indigenous	3.5-5.0	30.00
	Crossbred	4.0-5.5	43.00
Non dairy cattle (Indigenous)	0-1 yr.	3.5-4.0	7.00
	1-3 yr.	3.5-4.5	18.00
	Adult	3.5-5.0	35.00
Non dairy cattle (Crossbred)	0-1 yr.	3.5-4.0	8.00
	1-2.5 yr.	4.0-5.0	20.00
	Adult	4.0-5.0	48.00
Dairy Buffalo	Adult Lactating	4.0-5.5	56.00
Non dairy Buffalo	0-1 yr.	4.0-5.0	10.00
	1-3 yr.	4.0-5.0	25.00
	Adult	4.0-5.5	36.00

*Methane conversion factor: The methane conversion factor is the proportion of feed energy converted to methane (percent of gross energy consumed).

#Methane emission factors: Methane emission factor is the average annual emission of methane per animal (kg/animal/year)

Methane emission from manure management

Methane emission from manure management of all livestock species has been calculated on the basis of default emission factors as recommended by IPCC (1996).

Confidence level of the coefficients, quality assurance and quality control

Body weights of different category of animals have been categorized in relation to age group in different states. Feeds and feeding system followed have also been considered and variables related to stall-fed, rangeland feeding, working hours of bullocks and weight loss during lean seasons have also been considered as per IPCC methodology. The methane emission factor (EF) based on methane measurements of representative feeds and fodders have been measured and relevant MEF have been used. The present emission rates are based on a mid value of 65% though range for digestibility is vast from 53 to 80. The maximum variations are assumed to be about 5% in DE and about 5-7% in body weights. The total variability is observed to be 5-7.5 % in dairy, working and other animals for any particular

region or state. However, at all India level the variability is likely to be neutralized due to large variations in the managament conditions and types of livestock. Assuming all variations the overall confidence level may be taken as about 5% but we expect about 8-10% variations in the present inventory as a safety measure. QA/QC checks address input data values, formulae, and summation procedures. The quality of much of the input data depends on the procedures of the organizations providing the data (e.g. Agricultural statistics, etc). Documentation of their QA/QC procedures was not readily available. For this inventory, particular attention was paid to the checks on the feed digestibility and methane conversion values based on literature review. The accuracy of methane measurements was checked by gas measurements for the standard sample of methane on gas analyzers.

Methane emission levels

The total emission of methane from 485 million animals has been estimated about 9.37 Tg for 2003 (Table 3). Buffaloes contributed 3.8 Tg (40.0%), Indigenous cattle 3.75 Tg (40%), crossbred cattle 0.71 Tg (8.0%) and contribution of sheep and a goat was 0.96 Tg (10%). The other livestock with minor population consisting of Equines (Horses, ponies, Mules and donkeys), pigs, yak, mithun and camels contributed only 2% (0.15 Tg) of total emission from livestock sector. The ruminants, both small and large, were the main contributors (98%) to the enteric methane emission in India.

Table 3. Total methane emission from Indian livestock in 2003

Species	Enteric Fermentation (Tg/year)	Manure Management (Tg/year)	Total Emission (Tg/year)
Indigenous Cattle	3.34	0.41	3.75
Crossbred	0.63	0.08	0.71
Buffalo	3.34	0.46	3.8
Sheep	0.31	0.01	0.32
Goat	0.62	0.02	0.64
Others	0.09	0.06	0.15
Total	8.33	1.04	9.37

Indigenous female cattle (82.9 million) contributed 2.2 Tg and 77.53 million indigenous males emitted 1.55 Tg methane. Crossbred females though in small number compared to indigenous cattle, emitted more methane per animal (0.63 Tg methane from 19.74 million heads) indicating that crossbreds produce more methane than indigenous animals. The emissions from buffalo females were also

higher, due to large body size compared to Indigenous cattle, and 80 million females produced 3.42Tg in 2003. The contribution of buffalo females was about 36.5% to total methane emission from livestock sector. Dairy cattle and buffaloes contributed 3.42 Tg methane in 2003. The contribution of milch buffaloes was 59.6 %, crossbred cows 11.4% and Indigenous cows 28.9% to the total emissions from dairy animals.

The enteric methane emissions from working cattle and buffaloes have been observed to be about 15 kg/annum for 250 kg bullocks and 25 kg/annum for animals weighing above 500 kg. The working crossbreds and buffaloes on an average produce more methane ranging from 18-22 kg/head /annum. The total emission from draught animals has been estimated 1.2Tg. The contribution of bullocks (indigenous and crossbreds) was 85%, buffalo males 10% and other transport and pack animals contributed about 5% of total methane emission. The emission from indigenous cattle was 0.92 Tg and small sized bullocks weighing 250 kg produced 0.34 Tg. Medium sized bullocks contributed 0.40 Tg, large bullocks and heavy bullocks contributed 0.17 Tg due to their small population size. The contribution by large working crossbred bullocks was more than that of other groups due to their requirements for heavy weights therefore contribution of crossbreds working males is more to methane emission per unit of work output. The emissions from buffalo males were also more due to heavy weights. The methane emissions from indigenous small bullocks working for 50, 100 and 200 days was 0.10, 0.11, 0.13 Tg and respective values for medium sized bullocks were 0.12, 0.13, 0.15 Tg. The contribution of both crossbreds and buffaloes was 0.13Tg by different category of weights.

The total methane emitted due to enteric fermentation and manure management of 485 million heads of livestock has been worked out at 9.37 Tg/annum for the year 2003 (Upadhyay et al. 2007, 2008) on the basis of IPCC methodology. Comparison of methane emission factors for enteric fermentation used by various organization are given in Table 4. The indigenous, crossbred cattle and buffalo, respectively contribute 40%, 8%, and 40% to methane emission. Lactating animals comprising of buffaloes and cattle contributed 3.42 Tg with a major share of 2.04 Tg from lactating buffaloes. Draught animals emit about 1.2 Tg methane/annum. Working bullock on an average produces 40-50 gm methane per day. Methane emission due to enteric fermentation from working cattle and buffaloes is 90-100 g/hp/day or 35-40 kg/annum for an average bullock. Working buffalo males produce about 7-10 kg/annum more methane than indigenous bullocks.

Table 4. Comparison of methane emission factors (kg CH$_4$/animal/year) for enteric fermentation

Category	Sub category	IPCC default	NDRI	CLRI	ALGAS	NDRI*
Dairy cattle	Indigenous	46	33	23	23	30.00
	Crossbred	46	39	42	32	43.00
Non dairy cattle (Indigenous)	0-1 yr.	17	8	6	4	7.00
	1-3 yr.	25	16	23	16	18.00
	Adult	25	31	27	20	35.00
Non dairy cattle (Crossbred)	0-1 yr.	17	10	9	5	8.00
	1-2.5 yr.	25	21	28	10	20.00
	Adult	25	33	29	29	48.00
Dairy buffalo	Adult	55	69	38	32	56.00

* Values based on MEF as per IPCC methodology using MCF measured by open circuit and Douglas bag.

The Indian breeds of livestock have capacity to withstand thermal stress, feed and water scarcity, diseases and parasite load. Methane emissions from Indian livestock, though low per animal but are high per unit of production due to large unproductive population. The productivity per unit livestock is also low and is a matter of concern for livestock development in India. Concerted efforts should be made to improve productivity and efficiency of production without increasing GHG emissions from Indian livestock. Both feed and fodder management and proper livestock waste management can help mitigating methane emission.

References

IPCC (1996) Good practice guidance and uncertainty management in national greenhouse gas inventories. Inter: Governmental Panel on Climate Change, Bracknell, USA.

Ranjhan SK (1999) Animal Nutrition and Feeding Practices; Vikas Publishing House, New Delhi.

Singh G (1999) Characteristics and use of draught animals power in India. Indian Journal Animal Science 69 (8): 621–627

Swamy M and Shashirekha V (2004) Country specific emission coefficients for estimation of methane from livestock. In, proceedings of the workshop on uncertainty reduction in greenhouse gas inventories. National Physical Laboratory, New Delhi, March 4-5, 2003. pp 128-138.

Upadhyay RC, Gupta SK, Kumar A, Singh SV and Ashutosh (2007) Uncertainty reduction in methane emission from Indian livestock: IPCC methodology (Abstract). 2nd Intl W'shop Uncertainty reduction on GHG, Austria.

Upadhyay RC, Gupta SK, Kumar A, Singh SV and Ashutosh (2008) The contribution of draught animals to methane emission in India. Draught Animal News, 46 (Part-1), 29-36.

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