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AMARON

Preface

Climate change and variability poses major threats to mangrove and agricultural ecosystems. Mangrove ecosystem in general and Sundarban-mangrove in particular plays an important role in climate change mitigation, however, it is also affected by negative impacts of climate change particularly sea level rise and global warming. Mangrove ecosystem is a significant sink as well source of greenhouse gases (GHGs). It not only absorbs huge quantity of carbon dioxide from atmosphere and cleans the environment but also acts as physical barriers in-between seas and habitat of island of Sundarban and protects the mankind from extensive vagaries of cyclones and extreme climatic events. Unfortunately, this valuable ecosystem is under threats due to burgeoning human influence and sea level rise. In last century itself, 40% of mangrove is lost from earth. In Sundarban, India the "mangrove-area" decreased from 2387 km^2 to 2136 km^2 from 1930 to 2013 (~10%), primarily due to intervention of agriculture (rice cultivation and aquaculture) and human activities. In reality, in last century to till date the degraded mangrove-agriculture (primarily rice) in Sundarban represents a typical ecosystem that has different biological diversities, carbon and GHGs budgeting.

In this research bulletin, we try to document the techniques for estimation of GHGs in degraded mangrove-rice ecosystem with clear cut principles, procedures along with limitations and advantages of each technique. Precisely, four techniques namely "bubble collection chamber", "water-atmosphere exchanges", "manual close chamber method" and "eddy-covariance technique" are discussed in details in order to estimate the three mode of transport of GHGs from soil/sediment to atmosphere in mangrove-rice ecosystem. The "bubble collection chamber" is used for capturing the GHGs fluxes through ebullition process (through bubbles), whereas, the "manual close chamber method" is used for estimating the GHGs fluxes from soil/sediments to atmosphere. In order to estimate the "water-atmosphere GHGs exchanges" dissolved gases both in stagnant water in sediment' cracks and tide water is considered with wind velocity. And the sensor based eddy covariance technique is discussed for getting the GHGs footprint of the system as a whole on real time basis.

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Authors

1. Introduction

Mangroves are bio-geochemically important transitional coastal ecosystems in tropical and sub-tropical regions (Alongi, 2002; Kathiresan and Qasim 2005; Padhy et al., 2019). Those are of fundamental importance for establishment and maintenance of coastlines through their ability to filter water and play a critical role in maintenance of the food-chain and carbon cycle (Giri et al. 2011). The Sundarban is the world's largest contiguous mangrove. It is the part of the progradation delta of Ganga, Brahmaputra and Meghna rivers. The Sundarbans, found within 21°322 to 22°402 N and 88°052 to 89°512 E, covers an area of approximately 10,000 km^2, of which 62% lies within Bangladesh and 38% in India (Spalding et al., 2010). The mangrove has been lost globally mainly because of human interferences (e.g., habitat, agriculture, aquaculture, shoreline development) and sea-level rise. However, these ecosystems have been recognized as a crucial component in climate change mitigation strategies. Mangrove wetland ecosystems act as a source as well as a sink for greenhouse gases (GHGs) (Mukhopadhyay et al., 2002; Padhy et al., 2019), particularly carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The CO_2, CH_4 and N_2O are the major GHGs which are responsible for global warming. The atmospheric CO_2 concentration has increased rapidly from 278 to 414 ppm in 1750 to 2019 (NOAA, 2019), whereas, CH_4 and N_2O have also been increased from 722 to 1803 ppb and 270 to 342 ppb, respectively (IPCC, 2014). The CH_4, CO_2, and N_2O contribute 20-25%, 40-50% and 5-10%, respectively towards global warming. The present rates of increase of these three gases per year are 0.41, 0.42 and 0.25%, respectively (IPCC 2014).Tidal mangrove wetlands are an important source of CH_4 and N_2O (Allen et al., 2007; Chauhan et al., 2008; Chen et al., 2010). Primarily, it represents a sink for CO_2 due to the high productivity of mangroves (Wang et al., 2016). These ecosystems are characterized by a high rate of nutrient turnover and an efficient source of organic matter. Mangrove ecosystems also favour the denitrification and methanogenesis processes due to the prevalence of anoxic conditions by tidal flooding (Krithika et al. 2008; Padhy et al., 2019). So, in virtue of these features, the systems behave like a potential source of CH_4 and N_2O. However, the high rate of nutrient turnover and small leaks in nutrient cycles in this system resulting in higher rates of GHGs emission.

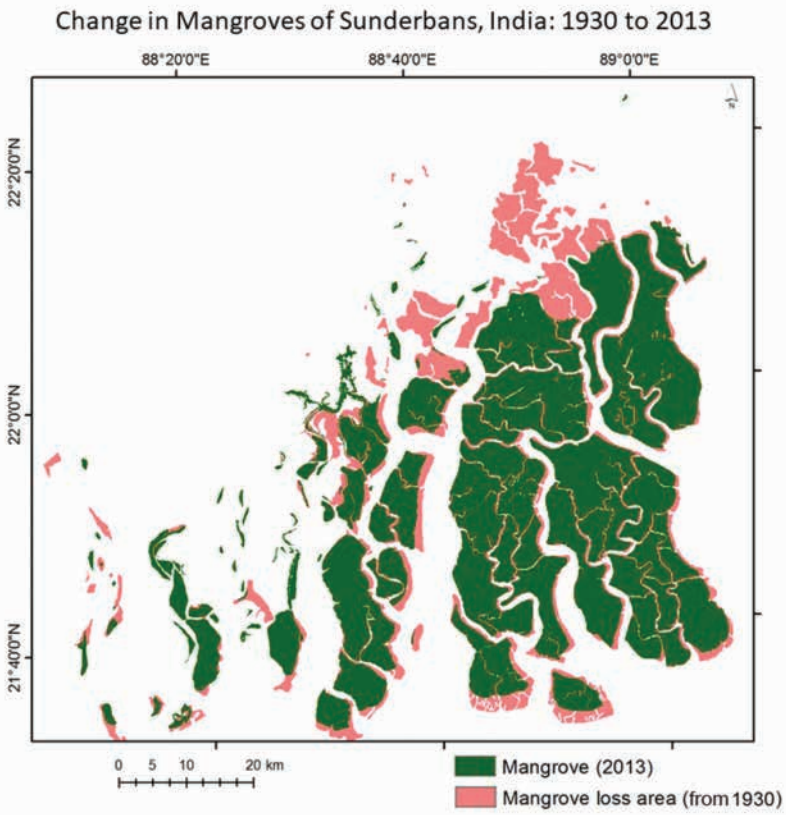

Figure 1: Degradation of mangrove from 1930 to 2013 in Sundarban, India

However, the temporal conversion of mangroves into agriculture (aqua-farms, rice-based systems) and climate induced adverse hydrological and geo-morphological processes resulted in reduction (35-40%) of mangrove vegetation. India has lost around 40 percent of its mangrove area in the last century due to its conversion to habitat, aqua-farms and agriculture (rice and rice-based systems). In Sundarban, the 'mangrove-area' decreased from 2387 km^2 to 2136 km^2 from 1930 to 2013 (Figure 1). Therefore, in last century or so the degraded mangrove-agriculture (primarily rice) in Sundarban represents a typical ecosystem that has different GHGs fluxes/emissions and carbon budgets.

In the degraded mangrove-rice system the GHGs emissions from sediments to the atmosphere occur through different passages and or

medium. Mainly, there are three modes of transport of GHGs from soil-water system to atmosphere that causes emission. First one, is through the aerenchyma of pneumatophores (negatively geotropic breathing roots of mangrove), second one, is diffusion from the soil through ebullition (through the bubble) and the third one is water-atmosphere exchanges (governed by dissolution and diffusion of GHGs in water; dissolved in either stagnant or tide-water) (Purvaja et al., 2004; Dutta et al., 2015; Padhy et al., 2019). However, there exits some uncertainty. Particularly, due to the fact that gas transfer velocities in mangrove-surrounded waters are not well defined/determined that leads to uncertainty in air-water fluxes. Although, we know the basic principles behind the three modes of transport from soil-water system to atmosphere which causes GHGs emission in mangrove ecosystem, but the capturing of the all three mode of transport at a single point of time on the specific site of interest is challenging. Particularly, capturing the fluxes through bubbles and pneumatophores of mangrove is very tedious and labourious. Further, the ecology of Sundarban itself is not congenial for direct field sampling due to harsh-climate and wild animal threat. These factors make a lot of uncertainty on-field GHGs flux measurement in Sundarban mangrove system.

The three modes of transport of GHGs fluxes/emissions could be well differentiated by the condition and the mechanism (Figure 2). The gaseous flux from sediment is measured to capture the fluxes through the pneumatophores (through aerenchyma tissues) of mangrove, whereas, the emission through ebullition is quantified to capture the fluxes through bubbles/soil pores, specifically during tide and sudden water intrusion. During the tide, all of a sudden, the air-pores in the sediments are filled with water and the air/gas removed from the sediment as bubbles and the hysteresis effect (filling of pores with water and drying of water-filled soil pores) was also there. Apart from this, when the tide-water is stagnant in sediment-cracks or large pores for 8 to 10hrs daily, the GHGs concentration in water increases and that represents a significantly portion of non-point source of GHGs emission. Water-atmosphere exchanges in non-point sources of GHGs could be captured in dissolved GHGs concentration in surface water which is generally not accounted for gaseous flux measurement.

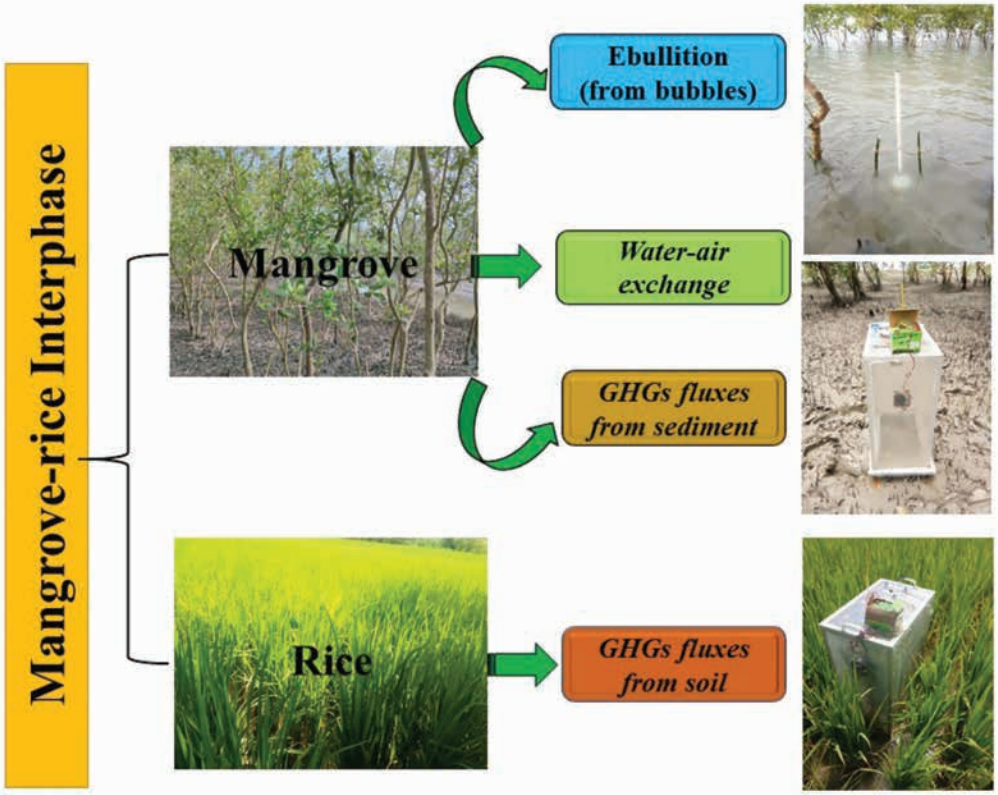

Figure 2:Three mode of transport of GHGs fluxes/ emissions in degraded mangrove-rice ecosystem.

2. Importance of the work

- Indian mangroves occupy an area of 6740km^2; seven per cent (7%) of the world's mangrove. Sundarban (in W.B) is the largest deltaic mangrove forest in the world (4263 sq km); along with that the Bhitar Kanika (Odisha) (243 sq km) in eastern India are the vulnerable zone in climate change vagaries.
- Sink-source behaviors of GHGs and carbon have changed in degraded mangrove-rice ecosystem compared to undisturbed mangrove which leads to positive feedback to climate change.
- There is a need of site-specific quantification of GHGs emission in mangrove (protected) in general and degraded mangrove-rice system in particular.

- The specific techniques of estimation of GHGs emission through ebullition (fluxes through bubbles) and water-atmosphere are not well documented.

3. Research Gaps

- Data on GHGs emission inventories are sparse in Sundarban mangrove as well as degraded mangrove-rice ecosystem in India.
- On field, site-specific techniques for estimation of ebullition-GHGs flux and water-atmosphere GHGs exchange is limited.
- Integrated approach (with technique specific) for capturing all the three mode of GHGs transport in degraded mangrove-rice ecosystem is lacking.
- Quantified data on seasonal and annual fluctuation of the three major GHGs like, CH_4, CO_2 and N_2O in degraded mangrove-agriculture system is a gap.

4. Different techniques used for GHGs fluxes measurements from mangrove sediments

A precise estimate of the amount of GHGs released from mangrove soil/sediment into the atmosphere is of great importance in understanding the role of microbes and soil salinity in regional and global climate change and in the global carbon budget. However, progress in quantifying the amount of GHGs released into the atmosphere through these pathways have been hindered by the uncertainties involving the total area involved, the temporal variability and site-specific human interferences In recent years, much attention has been paid to the long-term *in-situ* measurements of the GHGs flux to study the spatial-temporal variability at specific vulnerable locations.

4.1. Greenhouse gases flux estimation in ebullition process (GHGs emitted through bubbles) by the 'bubble-collection chamber'.

4.1.1. Basic units of the 'bubble-collection chamber' and measurement procedure

The GHGs emission through the ebullition process is estimated by entrapping the gas bubbles from the sediments of the mangrove system. A unique innovative structure with small collection volume and long tube

for gas collection is used to take care of gradual increasing depth of tide-water over time and restricting the chance of water leakage. This 'bubble collection chamber' is unique and portable in nature. The gas samples is collected by using an inverted plastic funnel (6.75 cm radius and 5 cm height) with cylinder base (6.75 cm radius and 7 cm height) fitted with a silicone rubber septum at the top of the stem (2.4 cm radius and 82 cm height) (Figure 3). During the time of sampling, the base is inserted into 1 cm inside the sediments for making the system airtight. The volume of the chamber is estimated by adding the volume of base-cylinder, funnel, and stem. Bubble-gas samples are collected in two different situations, i.e. before and during the tide. Gas samples are collected at '0' minute and '30' minutes for getting the half an hour flux (30 min). After collection, the gas samples are analysed in the gas chromatograph (GC) for estimating the concentration of CH_4, CO_2 and N_2O.

The GHGs fluxes are estimated by using the formula,

GHGs flux= (Difference GHGs concentrations at 30 min and 0 min × Chamber volume × Molecular weight of the GHG)/(Area of the base × Time interval between initial and final sampling).

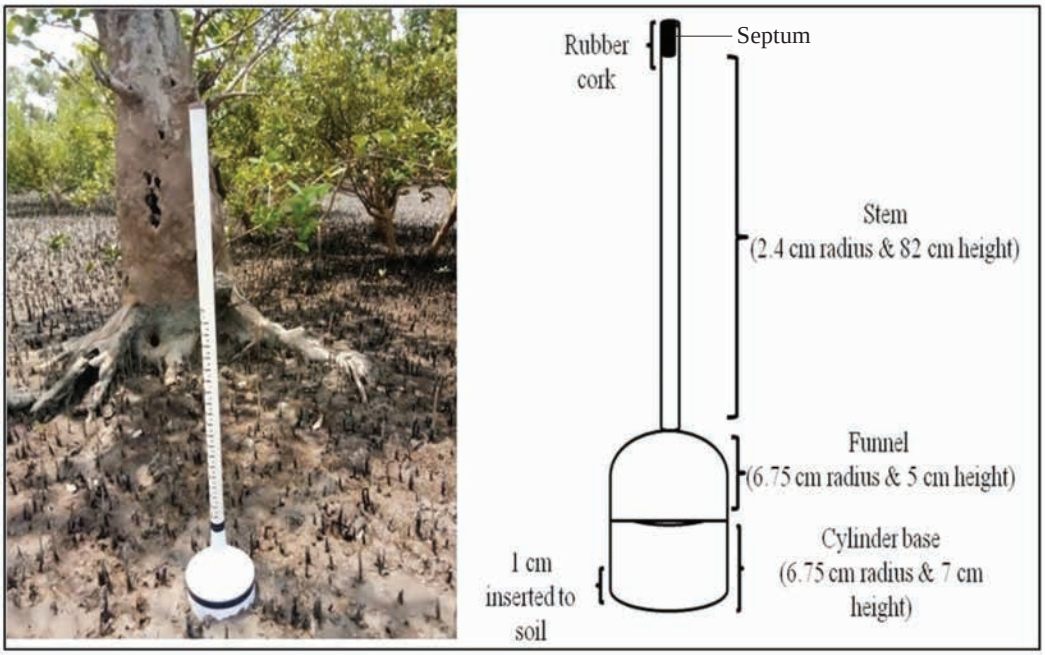

Figure 3: Greenhouse gas sampling by using "bubble collection chamber" for capturing the GHGs fluxes through ebullition in degraded mangrove-rice ecosystem in Sundarban, India

4.1.2. Advantages

- Very easy and cheap method to trap gas bubbles.
- Easy-to-handle equipment.
- It is portable one, so tidal fluctuation could be addressed effectively.
- Diurnal variation could be captured through high frequency sampling.
- Time and site of measurement could be customized according to the objectives of the study.
- The trap ("bubble collection chamber") described here can be adapted to measure a varying range of ebullition fluxes by altering the diameter and length of the collection chamber.

4.1.3. Limitations

- It is a point measurement.
- Keeping the assembly in airtight condition during gas collection is difficult and laborious.
- There is no provision of temperature correction.
- In this method, sometimes it is difficult to segregate the fluxes originated from bubble-ebullition or through soil/sediment cracks.

4.1.4. Key points to be remembered

i. In situations where the "bubble collection chamber" is only be partially submerged due to low tide water-intrusion, the air from the collection chamber should be removed at the beginning of deployment by applying a mild suction, for example using a syringe.

ii. The sediment-chamber interphase should be air tight. There should not be any leakage.

iii. Proper anchoring of the "bubble collection chamber" assembly in sediment is essential. Otherwise the stability of the assembly can be disturbed during tide-water intrusion.

iv. The "bubble collection chamber" should not float during the gas collection period.

v. The ratio of "collection chamber" and the "collection-pipe" at which the gas is collected by syringe must be optimized/modified according to the site-characteristics, sediment- structure and tide-water influence.

vi. At least 2 sampling should be done per day.

4.2. The water-atmosphere GHGs exchange

4.2.1. Working principles and basic units

The GHGs exchanges in water-atmosphere interphase were estimated by collecting surface water samples from stagnant water (6 to 8 hrs) in sediment cracks, during tide and also after tide (30minutes). The concentration of dissolved GHGs in water, wind speed, partial concentration of gases are taken into account for estimating GHGs exchanges in water-atmosphere interphase. Specifically, after collecting the surface water in 100 mL serum bottle, 0.1ml of saturated mercuric chloride ($HgCl_2$) has to be added in the serum bottle to inhibit the microbial and phytoplankton activities. The bottles are tightly sealed and should be transported safely to the laboratory with proper care. Exactly, 50ml of the collected sample in each bottle is subsequently replaced by nitrogen (N_2; pre-flushed) (Figure 4). Then the bottles with the remaining water samples are shaken for 10 minutes. After that, the gas is taken from headspace of the serum bottle and analyzed in gas chromatography. The dissolved GHGs concentrations are expressed as µmol L^{-1} for CO_2 and nmol L^{-1} for CH_4 and N_2O (Padhy et al., 2019).

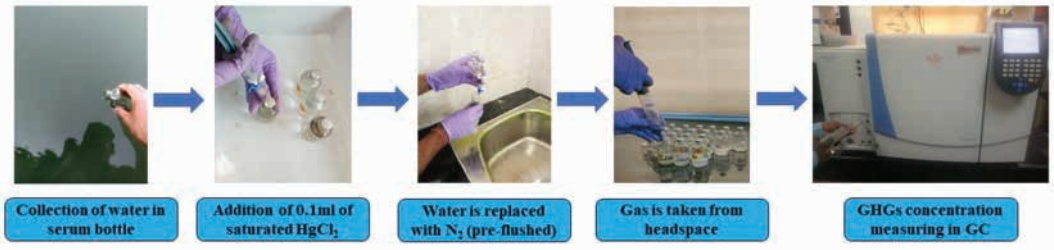

Figure 4. Liquid sample collection and estimation of dissolved GHGs in water sample

Calculation of water-atmosphere GHGs exchange

The water-atmosphere GHGs exchange is estimated by using the techniques considering the gas transfer velocity and solubility coefficient of GHGs (Jiang et al., 2008; Ho et al., 2014; Padhy et al., 2019).

Water - Atmosphere GHGs exchange (F) = $k.K_0.(pGHG\ water - pGHG\ air)$

Where, k (cm h^{-1}) is the gas transfer velocity, K_0 (mol L Pa^{-1}) is the solubility coefficient of the GHGs (Wiesenburg and Guinasso (1979) for CH_4, by Weiss and Price (1980) for N_2O and by Weiss (1974) for CO_2); $pGHG_{water}$ and $pGHG_{air}$ are the partial pressure of GHGs in the water and the atmosphere, respectively. And the gas transfer velocity (k) is estimated by using the formula(Jiang et al., 2008),

$$k = (0.314\ u^2 - 0.436\ u + 3.990) * (Sc\ /\ 600)^{-0.5}$$

where, u is the wind speed at 10 m height (m s^{-1}) and Sc is the Schmidt number, which is calculated as a function of the temperature using the expression given by Wanninkhof (2014).

4.2.2. Advantages

- It is widely accepted procedure to estimate GHGs exchange in water-atmosphere interphase in estuaries and mangrove ecosystem.
- It can be up-scaled in larger area of interest.
- It considers both water and air specific properties related to GHGs fluxes.
- Monthly, seasonal and annual flux variation of GHGs exchanges could be quantified.

4.2.3. Limitations

- Wind (speed and direction) variation at micro or point level, where concentration of gases is measured is sometimes difficult to be addressed.
- Tide frequency and volume is not considered during estimation.
- Sampling point in water bodies and its distance from sediment/ land area need to be specified.

4.2.4. Key points to be remembered

i. Wind speed and direction considered for the estimation must be matched with time of water sample taken.

ii. Solubility co-efficient of GHGs in water when considered the salinity of water must be addressed.

iii. It is the GHGs exchanges in water-atmosphere interphase; so time lag of sampling needs to be reduced at non-significant level.

4.3.The GHGs fluxes from sediment/soil in degraded mangrove-rice ecosystem

Greenhouse gas samples are first collected from soil-plant systems in the field with the help of specifically designed "close chamber" and then concentrations of collected gas samples are measured through gas chromatography. The flux or emission from soil-plant systems then estimated as a change in concentration of desired gas at unit time (gas collection time in the closed chamber) in unit area (area represented by manual close chamber).The techniques could be used in degrade mangrove - rice system. The working principle of collecting from mangrove and rice system is same; only gas sampling procedure is different.

4.3.1. Working principle and basic components

- Greenhouse gas emission from degraded-mangrove and rice soil could be estimated by "manual close chamber method" with the help of a close-chamber. The gas samples are collected from the field and subsequently, the changes in concentration of the target gases are measured.
- The fluxes of the specific GHG during the study period is estimated with the help of change in concentration of the GHG per unit area per unit time assuming the linear change in concentration over the period (Bhattacharyya, 2016, 2019; Padhy et al., 2019).
- The chambers are preferably constructed by multilayered polycarbonate or perpex sheets. However, acrylic sheet or rigid plastic are also used.
- The dimension of the manual sample collection chamber is 57 cm × 37 cm × 71 cm (length x width x height) (Figure 5).

Figure 5: Schematic diagramand on field GHGs sampling from degraded mangrove-rice ecosystem.

- Base plates with sharp base and channel are another basic and important component of this method must be placed permanently in the field (mainly, in case of rice field) or sometimes before sample collection (in mangrove ecosystem). It is generally made up of aluminium frames with desired dimension, so that chamber can suitably place on that. It must be inserted 6-12 cm inside the soil, based on soil type, method and amount of irrigation and type of crop. The base plate-channels should be filled with water before putting the chamber on it to make the base plate-chamber system air-tight.
- The mixing of air inside the chamber must be ensured to get the representative homogeneous gas samples. Therefore, either fans (two or more at top and bottom) need to be used to homogenize the air inside the chamber during sampling.
- As the expansion and contraction of the volume of the gas depends on temperature and pressure, those must be monitored inside the chamber during the sampling period.
- The initial as well as high frequency periodical sampling is prerequisite for the precise GHGs measurement.
- The second step, is the estimation of concentrations of GHGs of the collected gas samples with the help of gas chromatograph (GC). Immediate analysis in GC is necessary to prevent the diffusion loses of gas concentration.

4.3.2. Procedure of collecting the GHGs from soil/ sediment in degraded-mangrove-rice system by 'manual close chamber method'

Placement of base plates in targeted location, where we want to take measurement prior to sowing/ transplanting in case of rice and also in particular mangrove site.

↓

Pouring the water in the groves or channel of the base plate and then Placing the chamber on the base plates.

↓

Observe the temperature of the inside the chamber at zero minute. At the same time record the depth of ponding in the field. That is the height of water in the field both inside and outside of the chamber.

↓

Collect the gas sample at zero minute with the help of syringe through the septum.

↓

Keep the chamber in the field for 15 and 30 minutes. And collect the gas samples at 15 and 30 minutes again with the help of syringe. Temperature and ponding water depth of the field also should be noted at that time.

↓

The syringe should be air-tight with stopcock immediate after collecting the gas samples.

4.3.3 Analysis of GHGs concentrations by Gas Chromatography (GC)

Methane, nitrous oxide and carbon dioxide concentrations of the gas samples collected through "manual chamber method" could be precisely analysed by gas chromatography (GC) equipped with flame ionization detector (FID), electron capture detector (ECD) and flame ionization detector (FID) fitted with a methanizer, respectively.

Equations for the Calculation of GHG fluxes

$$CH_4\ flux\ (mg\ m^{-2}\ hr^{-1}) = \frac{(\Delta X_{CH4} \times EBV_{STP} \times 16 \times 60 \times 10^{-3})}{22.4 \times A \times T}$$

$$CO_2\ flux\ (mg\ m^{-2}\ hr^{-1}) = \frac{(\Delta X_{CO_2} \times EBV_{STP} \times 44 \times 60 \times 10^{-3})}{22.4 \times A \times T}$$

$$N_2O\ flux\ (\mu g\ m^{-2}\ hr^{-1}) = \frac{(\Delta X_{N_2O} \times EBV_{STP} \times 44 \times 60 \times 10^{-3})}{22.4 \times A \times T}$$

Where, ΔX = Difference in concentration value between 30/15 min and 0 min (converted to ppm based on the standard values), $EBV_{(STP)}$ = Effective box volume at standard temperature and pressure, T = Flux measurement time in min (15 or 30), A = rice crop area / pneumatophore area of mangrove occupied by the box in m^{-2} (length × breadth).

The $EBV_{(STP)}$ is calculated using the following equation,

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

Where, P_1 = Barometric pressure at the time of sampling in mm Hg, V_1 = EBV (Effective box volume), T_1 = 273°K + temperature inside the box at the time of sampling in p C, P_2 = Standard barometric pressure (760) in mm Hg, V_2 = $EBV_{(STP)}$, T_2 = 273°K

The Effective box volume (EBV) is calculated using the following equation:

$$EBV = Box[(H - h) \times L \times B] - V$$

Where, H = Box height (cm), h = Height of the field water level (cm), L = Box length (cm), B = Box breadth (cm), V = Crop (e.g. rice/pneumatophores) biomass volume (mL) inside the box (above ground biomass only).

4.3.4. Advantages

- The chambers and accessories are simple, economic and easy to make with locally available material.
- The size and dimension of the chamber is flexible and could be modified according to the need of the study/work.
- Treatment differences could be captured even in small plots and moreover, very small changes in fluxes can be detected.
- It is a stand alone system with a small battery could be solar operated and no extra power supply is required.
- It is easy to handle; so no extra skill or specific training is required to collect the samples.
- Little disturbance to the crop during sampling.

4.3.5. Limitations

- End point inhibition on fluxes may be happened due to accumulation of gases during sampling time. So normal emission rate might be distorted.
- Enhancement of temperature and or pressure inside the chamber during sampling time may lead to underestimate the fluxes.
- It would give only point data for a specific time; so diurnal variation rarely capture unless high frequency sampling is done throughout the day which is laborious and difficult to execute in field condition.

4.3.6. Key points for sampling and analysis

- Chamber size should be such that minimum representative plant number accommodate there. As for example in case of rice, six hills must be there inside the chamber.
- Zero-minute gas sampling is important; it should be measured precisely. So, first gas sample inside the chamber should be taken immediately after placing the chamber on the base plate.
- Gas samples should be taken in reasonable time intervals (15, 30 minutes or 10, 20, 30, 40, 60 minutes) based on the objective of the study. So that fluctuations of gas concentrations in headspace could be detected precisely. Very short or longer chamber deployment durations may result erroneous output.
- More number of deployments of chambers is advisable in order to reduce the spatial variability.
- The temporal variability should be reduced by increasing the sampling frequency.
- Longer period (30 minutes) of sampling results in better precision however too long (> 2 hour) period may result sampling artefacts.
- To avoid the diurnal variation, the gas samples should be collected twice in a day preferably at 9-11 AM in morning and 3-5 PM in the evening.

4.4. Eddy covariance system for GHGs measurement

4.4.1. Working principle

The eddy refers to the small three-dimensional pocket of wind that has both magnitude and direction. The eddy covariance method is actually the covariance between vertical component of wind speed and concentration of desired gas at a particular moment. It is a micrometeorological technique generally uses to estimate the turbulent fluxes of GHGs (CO_2, CH_4, etc.), water vapour, heat and organic volatile compounds in the boundary layer of atmosphere. This technique or method is also popularly known as "Eddy Flux Technique". It gives direct measurement of turbulent flux of a gas (e.g. CO_2/CH_4 /H_2O vapour) across the horizontal wind streamline near or above plant canopy (Baldocchi et al. 2000). In this method high frequency (10, 20, 40 Hz) time series data of wind speed and gaseous concentrations are used for flux calculation. The positive "eddy flux" represents the emission (outgoing) of GHGs/gases from the system at sensor height, whereas, the negative eddy flux indicates the uptake (absorbed) of GHGs/gases in the system. It is an advanced, highly precise, stationary, real time system widely used throughout the world.

4.4.2. Basic components of Eddy Covariance system

The basic unit of eddy covariance system includes three-dimensional sonic anemometer, carbon dioxide and H_2O gas analyser, data logger, power supply unit, either flux tower or tripod for sensors holding and data processing softwares.

(i) Three dimensional sonic anemometer

Three-dimensional (horizontal, vertical, and longitudinal) wind speeds is measured by sonic anemometer with high frequency (10 Hz), i.e. millisecond data.

(ii) Carbon dioxide and H_2O gas analyser

High frequency and sensitive infrared gas analyser (IRGA) is used for measuring the concentration of CO_2 and H_2O vapour. It is sensor-based technique. Calibration of the analyser should be done against standard pure CO_2 (99.99%) for carbon dioxide and dew point generated for water vapour.

(iii) Data logger

Data logger is an electronic device used to collect, store and retrieve large amount of time series data of sensors (Sonic anemometer, IRGA). Actually, it is an analyzer interface unit to collect and store data by the Ethernet.

(iv) Power supply unit

Eddy covariance system is a standalone stationary system. It gets power from battery which could be recharged through appropriate solar panel. Generally, a well-designed photo voltaic power system is used to supply continuous power to the system.

(v) Flux tower and tripod

The eddy covariance system could be installed either on flux tower (2 m of each stretch/compartment) at around 10, 20 or 30 meter height based on the canopy height (Figure 6) or in tripods (2-3 meter height). The flux tower primarily installed in forest ecosystem and horticultural or agro-forestry system. While, tripods system is used in agricultural crops and pastures. There are well networked flux system exist in Europe, Asia and America named as "Euroflux" (CARBOEUROPE), "Asiaflux" and "Ameriflux", respectively. And the data based is popularly known as 'FLUXNET' database.

(vi) Data processing software

Eddy covariance systems generate huge volume of real time "time-series" data (high frequency data). If needs user friendly, flexible software for processing the raw data considering relevant corrections. The software should have platform to import different time series data format, allow configuring sampling rate, configuring auxiliary sensors inputs. Currently, many types of software are available for processing high frequency time series data. Those are TSA, TK2, EdiRe, EC pack, EddySoft, EdiPro etc. Most of the softwares used more or less similar basic empirical model/ equations/processes/approaches for processing the data with corrections. Therefore, output flux data generates not varied significantly. Only differences exist among the softwares are in processing speed, number of

corrections considers, type of input data used and numbers of estimated outputs.

4.4.3. Different sensor used in eddy covariance system

Apart from CO_2/H_2O analyzer (IRGA), and sonic anemometer the other sensors could be intergraded in eddy covariance system (Figure 7). Few other sensors are, (i)methane analyser; (ii)air temperature and relative humidity sensors; (iii)net radiation sensor; (iv) canopy temperature sensor; (v)four component radiation sensor; (vi) PAR sensor; (vii)soil heat flux plate; (viii) snow depth sensor; (ix) time domain refractometer; (x) tree-bale temperature; (xi) barometer processer; (xii) surface temperature sensor.

Figure 6: Typical open path Eddy Covariance System in mangrove field (Photo and schematic diagram).

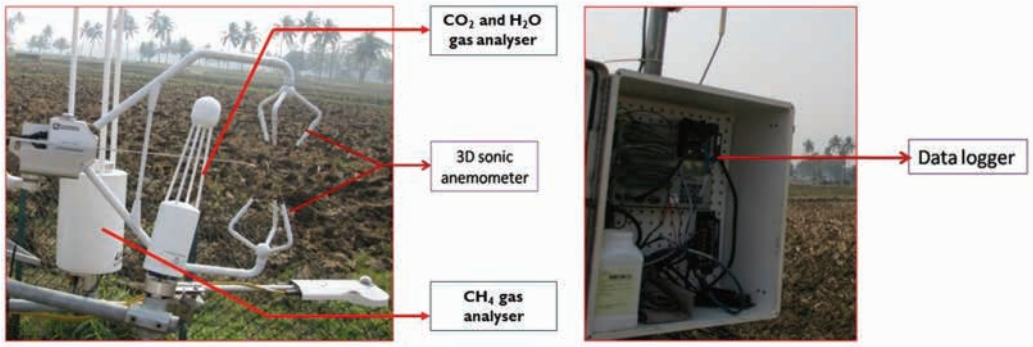

Figure 7: Basic components of Eddy Covariance system.

4.4.4. Eddy covariance data processing

Large amount of time-series data is generated by eddy covariance system. Initially, these data are saved in a specific data format (typical data format, e.g TOB 3 file format., etc) based on data logger capabilities. After that, those data are retrieved and processed through flux processing software (EdiRe, Edipro etc). Most of the time, software is taken care of correction, calculation and quality checks of time-series data by following definite algorithm (with empirical or process-based model/routine/sub-routine through software). However, processing software could be customized according to the need of the users and the objectives of the studies.

4.4.5. Advantages

- It provides high frequency precise data.
- Non-destructive method of measurement; rarely disturbs the natural system.
- Provide real time *in-situ* data.
- Reliable and verifiable; It is an automated- data measurement technique.
- GHGs/carbon foot print analysis could be done very effectively with EC flux data.
- It could be widely used in mangrove, forestry, agriculture, horticulture and different land uses with high precision and could provide reliable data inventories in national and international scale.

4.4.6. Limitations

- It is relative costly instrument.
- It requires high frequency data measurement capability and un-interrupted power supply.
- Expertise and definite skilled personnel is essential for data handling and processing.
- The system is stationary and only provides real time data of a single system at a time.
- Correction of time-series data is essential; otherwise validity of data would be drastically reduced.

5. Upcoming challenges and issues to be addressed

i. Spatial level GHGs flux mapping in mangrove-rice ecosystem.

ii. Segregation of GHGs emission, particular water-atmosphere exchange from core (undisturbed) area mangrove with degraded mangrove-rice/ agriculture system.

iii. Delineating specific zone of degraded mangrove-agriculture (rice, aquaculture, etc.) ecosystem with characterized (disturbance, agricultural practices, etc.) land use and quantification of the GHGs emission in mangrove-rice interphase in relation to carbon pools and microbial diversity.

iv. The GHGs emission maps of Sundarban in degraded mangrove-rice ecosystem in Remote Sensing-GIS platform.

v. Prediction of GHG emission in Sundarban, mainly mangrove-rice ecosystem needs to be done in climate change scenarios.

vi. Large scale ground truthing of model-based up-scaling/prediction of GHGs emission is Sundarban region.

vii. Sensor based portable GHGs measurements/estimation techniques need to be developed and validated for getting real-time or site specific GHGs emission accounting, upscaling and prediction through model.

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