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Net ecosystem methane and carbon dioxide exchange in relation to heat and carbon balance in lowland tropical rice

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ABSTRACT

This paper reports on the annual net ecosystem exchanges of methane (CH_4), carbon dioxide (CO_2), sensible heat (H) and latent heat (LE) fluxes between tropical lowland rice and atmosphere as well as quantification of annual net ecosystem carbon (C) balance. This study included both wet and dry rice seasons and fallow periods as well. Cumulative annual net ecosystem CO_2 exchange (NEE) was -7.47 Mg C ha^{-1} and net ecosystem CH_4 exchange (NEME) was +419.68 kg CH_4 ha^{-1}, respectively, which were higher than the reported values in the same ecology. The range of NEE was much wider in dry season compared to wet season. However, NEME did not vary considerably between the seasons. As a whole, integrated NEE was 52% higher in dry season, whereas, integrated NEME was 24% higher in wet season. In lowland rice ecology LE outweighed H. The NEME showed positive correlation with H and LE in dry season, but the relationship of NEME with LE in wet season was negative. That might be due to changes in processes driving the methanogenesis versus methanotrophy in relatively dry soil and or less transportation of CH_4 from soil to atmosphere through rice. Annual global warming potential (GWP)-based C balance was done by considering net ecosystem production (NEP), rhizodeposition, algal biomass, root plus stubble biomass, ratoon and compost addition as ecosystem C input, whereas, NEME and nitrous oxide (N_2O) emission, C removal through harvest and dissolved organic C as ecosystem C outflux. Although (GWP)-based CO_2—C equivalent of CH_4 and N_2O emissions were sources of C loss from lowland rice ecosystem, but taking into account all the components of C balance within the system, this ecology reflected a good potential to store considerable amount of carbon (1.04 Mg C ha^{-1}) and hence, acted as net C sink. Future challenge is to quantify ecosystem carbon budgeting either by considering all sources of energy input and output and/or by using life cycle assessment method in lowland ecology and its up scaling.

1. Introduction

Understanding the response of terrestrial ecosystems to environmental changes on temporal scale is a key issue in changing climatic scenario (Law et al., 2002; IPCC 2014). As changes in weather and climate are closely inter-linked with land surface processes, therefore, attention has been given for establishing global networks for monitoring surface exchanges of matters (trace gases) and energy (heat fluxes, H and LE) between terrestrial, aquatic ecosystems and atmosphere (Marino et al., 1999; Morin et al., 2014; Gao et al., 2016). Agriculture is considered to be one of the major anthropogenic sources of atmospheric GHGs (Lal, 2000). Among terrestrial ecosystems, annual greenhouse gas (GHG) emissions from agricultural production in 2000–2010 were estimated at 5.0–5.8 $GtCO_2$ eq yr^{-1}, comprising about 10–12% of global anthropogenic emissions (IPCC, 2014) and contribute to regional C and heat budget. The natural as well as anthropogenic activities have serious effects on the GHGs emissions (Bouwman, 1990). Greenhouse gases differ in their warming influence (radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. Changes in the atmospheric concentrations of GHGs alter the energy balance of the climate system which leads to subsequent climate change. These GHGs have profound impact on global climatic changes resulting into increase in ambient temperature which is likely to affect agriculture. It is

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anticipated that increasing concentrations of GHGs are likely to accelerate further the rate of climate change (IPCC, 2014).

Croplands cover large areas of the globe and contribute significantly to the global C cycle. However, like other ecosystems, limited information exists on spatially explicit, ground-based estimates of C fluxes. Therefore, gaseous C and heat flux measurements of wetlands and agro-ecosystems (crop lands) and their response to environmental variables are vital for understanding the physiological behaviour of agro-ecosystems and predicting future climate change (Lobell and Asner, 2003; Patel et al., 2011).

Rice is grown in different environments ranging from tropical to temperate regions with varying climatic, edaphic, and biological conditions and agricultural management. Worldwide, more than 161 million ha land were used to rice (*Oryza sativa* L.), taking into account double and triple cropping (Kumar and Ladha, 2011). About 90% of this area is in Asia and within those two thirds in tropical Asia where rice is the most dominant crop grown during the wet season (FAO, 2009). Tropical *rainfed* lowland rice is grown using bunded fields that are flooded with rainwater for at least part of the cropping season. Enormous amounts of water are generally used in rice production. On an average, more than 5000 L of water are used to produce 1 kg of rice (Bouman, 2009**)**. Even, a significant portion of the total water requirement for rice production is used in land preparation. Rice cultivation is a unique anthropogenic manipulator of ecosystem C dynamics through uptake, fixation, emission and transfer of C among different pools. Study revealed that tropical low land rice ecology is a potential C sinks (Bhattacharyya et al., 2014**)** considering CO_2 and CH_4 exchange and related C pools. However, N_2O emission and GWP of non-CO_2 GHGs was not considered in that study. Rice paddies have a potential role in the global budget of GHGs such as CO_2, CH_4 and N_2O because they sequester the former but release the latter and their relative contribution changes with agricultural management practices (Miyata et al., 2000). Large variability exists in CO_2 and CH_4 fluxes in both spatial (with variability between or within paddy ecosystems) and temporal scales (with seasonal and diurnal variability) (Knox et al., 2015). Although a large number of field measurements of gaseous-C and N effluxes have been made in the past decade, their spatial coverage is still poor and extrapolating the results from point measurements to the global scale involves many uncertainties (USEPA, 2010).

Energy exchange in submerged rice ecosystems is considered as one of the most important processes as it affects air temperature, water transport, growth and productivity of plants (Pezeshki and DeLaune, 2012). The existence of floodwater, anaerobic soil or changes in the micrometeorological environment with submergence influence root activity, photosynthesis and respiration of rice plants. In this context, the eddy covariance (EC) based ecosystem heat exchange, CO_2 and CH_4 flux monitoring studies could provide important insight in ecosystem flux dynamics as well as C budgeting. The EC technique has been widely employed for CO_2, CH_4, water vapour and heat flux measurement in various parts of the world, especially in forests and grasslands, but there are few studies conducted on the tropical rice ecologies (Bhattacharyya et al., 2013a, 2014). Some researchers have been measuring NEE and energy exchange from lowland flooded ecosystem through open path EC (OPEC) system in rice ecology (Miyata et al., 2000; Saito et al., 2005; Alberto et al., 2009; Tseng et al., 2010; Alberto et al., 2011; Alberto et al., 2012; Bhattacharyya et al., 2013a,b; Bhattacharyya et al., 2014), however, the datasets are limited on NEME and GWP-based C budgeting in rice. Therefore, more primary field-level data on NEE, NEME and heat flux exchanges by using state-of-the art technology based OPEC system (Miyata, et al., 2000) in annual and inter-annual scales, including crop seasons plus fallow periods, are indeed needed for precise quantification and upscaling. This would improve our understanding on the contributions of GHGs from flooded rice ecology to global warming in changed climatic scenarios.

Continuous measurements of NEE are needed in order to determine the source-sink status of ecosystems and to analyze temporal variations of C exchange (Schmitt et al., 2010). NEE is influenced by factors like, phenological variability, temporal variation in moisture availability, seasonal and inter annual temperature fluctuations, canopy structure and variation in light intensity (Monson et al., 2002). At the same time, dynamics of NEME is also varying. Large portions of CH_4 formed in anaerobic condition may remain trapped in the flooded rice soil. Entrapped CH_4 oxidized to CO_2 when the floodwater is drained during the rice growing season or when the soil dries at the end of or after the rice growing season. But large amounts of entrapped CH_4 escape to the atmosphere immediately after the floodwater recedes (Wassmann et al., 2000). Therefore, large variability in NEME depends on CH_4 production, oxidation, and all these are influenced by water management, organic substrates in soil, Eh, air and soil temperature, methanogenic and methanotrophic bacteria (Meijide et al., 2011). It is difficult to correlate the CH_4 fluxes to any single meteorological variable or physical processes. However, pattern in the diurnal variation of the CH_4 fluxes was found quite similar to those of soil temperature, which gradually decreased from the afternoon through the night and increased from the morning to the afternoon (Yang and Chang, 1998). Further, in flooded rice paddy it was evidenced that higher air temperatures caused increased CH_4 emissions (Allen et al., 2003).

In this context it is important to have clear understanding of the processes and components of net ecosystem C budget (NECB) in tropical lowland flooded rice paddies to know whether the system is behaving as net C sink (net C accumulation in the system) or source (net C depletion or loss from the system). Agricultural activities which involve the C influx into the system are the addition of organic manures, rhizodeposition, aquatic biomass, CO_2—C fixation in the form of NEP, decayed roots and stubbles left over in the field. Whereas, the C outflux processes involve loss of C in the form of crop harvest and gaseous C emission (CH_4 and CO_2). So quantifying the balance between these two processes could provide a clear insight of C cycling under lowland rice paddy ecosystem which is required for maintaining ecosystem health and sustainability (Bhattacharyya et al., 2014).

On the basis of these considerations, the present study was conducted with the following objectives (i) to characterise NEE and NEME in relation to heat fluxes and (ii) to quantify the annual C balance of the ecosystem by considering GWP of GHGs in tropical lowland rice.

2. Materials and methods

2.1. Site description

The study site is located in experimental farm of Central Rice Research Institute (CRRI), Cuttack, Odisha, India (20° 27′ 6″ N latitude, 85° 56′ 25″ E longitude and 24 m above mean sea level). Mean annual highest and lowest temperatures were 39.2 and 22.5 °C, respectively and mean annual temperature is 27.7 °C. Average annual rainfall is 1500 mm. The soil of the site is an Aeric Endoaquept with sandy clay loam texture (25.9% clay, 21.6% silt, 52.5% sand), bulk density 1.42 Mg m^{-3}, pH (1:2.5 soil:solution ratio) 6.21, electrical conductivity 0.42 dS m^{-1}, total C 11.2 g kg^{-1} and total N 0.8 g kg^{-1}.

2.2. Crop establishment

The rice–rice cropping sequence included dry season (mid-January to second week of May 2014) and wet season rice (mid-July to third week of November 2014), and pre-and-post season fallow