Greenhouse gas emissions from agricultural land use in the coastal area of the Red River Delta

Abstract

This study aims to provide reliable greenhouse gas emission data from dominant land use types in the coastal areas of the Red river delta, Vietnam. The field measurements were conducted on freshwater paddy rice, paddy rice with salinity intrusion, rice-vegetable rotation, and continuous vegetables for two consecutive years. Greenhouse gases were measured for methane, carbon dioxide, and nitrous oxide. The results showed that annual CH_4 emissions were highest in the paddy rice with salinity intrusion (1852 kg C ha^{-1}), followed by freshwater rice paddy (971 kg C ha^{-1}), rice-vegetable rotation (102 kg C ha^{-1}), and continuous vegetable (7.8 kg C ha^{-1}). Annual N_2O emissions were the highest in rice-vegetable rotation (54.9 kg N ha^{-1}), followed by the continuous vegetable (15.5 kg N ha^{-1}), paddy rice with salinity intrusion (3.3 kg N ha^{-1}), and freshwater rice (2.7 kg N ha^{-1}). The CO_2 emissions fluctuate over the year. The paddy rice with salinity intrusion and freshwater paddy rice contribute to sequestration of 2000 kg C ha^{-1}. For continuous vegetable fields, CO_2 emissions are positive and higher in the rainy season. The global warming potential obtained highest in salinity intrusion rice paddy as it emits 17,177 kg $CO_{2\text{-eq}}$ ha^{-1} which is as twice the level in freshwater paddy rice (8,389 kg $CO_{2\text{-eq}}$ ha^{-1}) and rice-vegetable rotation (8,134 kg $CO_{2\text{-eq}}$ ha^{-1}). The continuous vegetable emits about 2,658 kg $CO_{2\text{-eq}}$ ha^{-1}. It is recommended to alter the paddy rice with salinity intrusion to other crops for better reduction of greenhouse gas emissions.

Keywords: *greenhouse gas; methane; carbon dioxide; nitrous oxide; land use; agriculture*

Introduction

Methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) has been contributing 60%, 20%, and 6% to global warming (Forster, 2007) and annually increasing up to 0.8%, 0.5%, and 0.3%, respectively (Stavi and Lal, 2012). Recent literature shows the annual increase of CO_2 (1.7% yr^{-1}) and CH_4 (1.3% yr^{-1}), reaching 34.9 $GtCO_2$ (Liu et al., 2022). Although the agricultural sector is not the largest source of greenhouse gas (GHG) emissions, it accounted for 13% of global anthropogenic GHG emissions with a significant amount of N_2O (60%) and CH_4 (50%) (IPCC, 2013). The main reasons for GHG emissions include crop management practices, inorganic fertilizers, animal manure, irrigation, and crop residue inputs (Metz et al., 2007, Dendooven et al., 2012). The CO_2 gas is released largely due to burning crop residues or microbial decomposition of soil organic matter (Muñoz et al., 2010, Cong et al., 2018) while CH_4 gas is produced during plant growth stage under flooded conditions (Mosier et al., 1998). N_2O gas is released from soils when the content of nitrogen exceeds plant demand under wet conditions (Davidson et al., 2000).

In Vietnam, agricultural activities are reported as the second highest GHG emission source accounting for 33% or 88.3 million tonnes of CO_2 equipment of the total GHG emissions. Among the diverse crop production, rice cultivation was identified as the largest source of GHG emissions (50.49%) accounting for 2/3 of total agricultural land in the country (Linquist et al., 2012). Other crops such as maize, potato, and vegetables were recently confirmed as the main source of N_2O from agriculture in Vietnam (Trang et al., 2019). The GHG emissions are varied at different agricultural land use types depending on the crop, cultivation practice and soil type, etc. (Zhou, 2017). Therefore, in the area where land-use change takes place rapidly like coastal areas of the Red River Delta (RRD) (Hoa et al., 2020) the emissions varied greatly over time and landscape. Changes in agricultural systems and practices led to soil carbon and nitrogen dynamics. Aerobic conditions affected the decomposition of soil organic carbon and mineralization of soil organic nitrogen (Takahashi et al., 2003), and change in the composition of soil microbial community (Chu et al., 2009) associated with greenhouse gas emissions (Nishimura et al., 2011, Stavi and Lal, 2012, Wang et al., 2013). These interactions lead to a significant spatial change in GHG emissions when shifting from one another land-use types.

Mono rice cultivation, rice-vegetables rotation, intensive vegetables, and fish ponds are dominant agricultural land uses in Vietnam. In the coastal area of the Red river delta (RRD), these land-use types can be found in the scattered and irregular spatial distribution within the landscape and there is also conversion between them over the years (Hoa et al., 2020). Thus, national GHG inventory with Tier-1 approach would result in a high estimation error. Therefore, it is very crucial for reliable quantification of GHG emissions from such land uses, which in turn will allow scaling up the national data with more accurate results i.e. using the land use, and land cover map (Kearney and Smukler, 2016). This is particularly important as Vietnam have not only agreed to accurately report their GHG emissions at national scale but also to prepare for mitigating anthropogenic GHG emission in the upcoming years, which may require an up to Tier-3 approach. However, GHG measurement availability in Vietnam is only officially available at national scales following the Tier-1 approach (Loan et al, 2020). Besides the general scarcity of crop management data, the estimation of GHG emissions from specific agricultural production systems is also constrained by the limitation of GHG measurement availability.

In this research, the dominant land use types (LUT) of coastal area including paddy rice with salinity intrusion (SRR), freshwater paddy rice (FRR), rice-vegetable rotation (RV), continuous vegetable (CV) were measured. The FRR, SRR, RV, and CV are typical agricultural land use with similar physio conditions to a vast areas in the northern of Vietnam. Therefore, a comprehensive measurement of GHG emission could contribute to an accurte estimation and insight into the understanding of interactions between GHG emissions and the physical environment. The field measurements were conducted for two consecutive years in Giao Thuy district, Nam Dinh province.

Materials and method

Study site

Giao Thuy district locates in the coastal area of the Red river delta with a total area of 237.76 km^2 and the altitude ranges from 0.5-1.5m above sea level. Due to the low topographical conditions, saline intrusion has been observed in coastal communes such as Giao Lac, Giao Xuan, and Giao Phong (Fig. 1). The popular agricultural adaptation practice was the conversions of mono rice to rice vegetable rotations or intensive vegetables or fishponds (Hoa et al., 2020). The average annual temperature in the district is 23.9 ^oC (T-min = 8.0^{o}C, T-max = 37.0^{o}C). There are two main seasons, rainy and dry seasons. The rainy season usually takes place from May to October, and the dry season occurs from November to April. The annual average rainfall is about 1,789 mm (Meteorological data acquired from Van Ly meteorological station during 2008 - 2017).

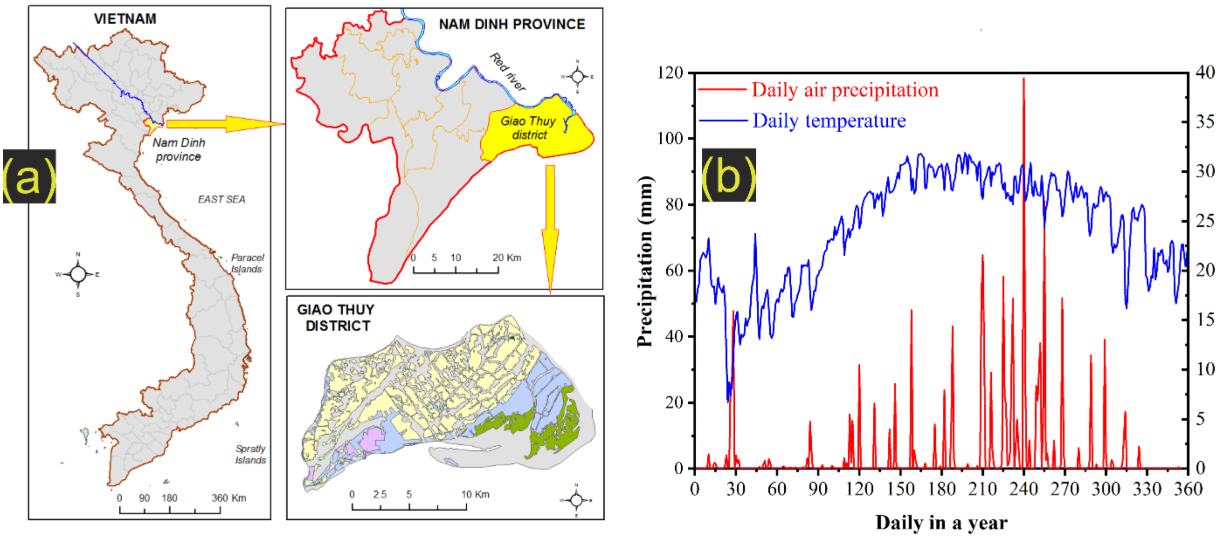

Fig. 1 Study site. (a) location of Giao Thuy district, (b) Daily precipitation and average air temperature in Giao Thuy district

Experimental design

The measurements of CH_4, CO_2, and N_2O emissions were applied at four main land-use types (LUT) including rice-vegetable rotation (RV), continuous vegetable (CV), paddy rice with salinity intrusion (SRR), freshwater paddy rice (FRR) during November 2015 to February 2017 (Table 1). The SRR and FRR are cultivated as double-rice crops (two seasons in a year). The winter-spring season started from February to June whereas the summer-autumn rice remained from August to October. On the rice-vegetable rotation fields, the autumn rice season was from July to October, then the different vegetables were grown from October to July next year. Intensive vegetables were cultivated four seasons a year in the fertile land areas. The GHG measurements and soil sampling were conducted to coincide with the crop growth calendar (Table 1). On each LUT, three plots were randomly placed for measurements. The crop types were managed by conventional irrigation, fertilizer application, and land preparation. In the study area, the annual rate of N fertilization is about 330 kg N ha^{-1} for rice fields, 876 kg N ha^{-1} for the rice-vegetable rotation system, and 705 kg N ha^{-1} for the continuous vegetable system.

Environmental parameters

Soil physicochemical properties were analyzed for 4 different land-use types at the beginning of the experiment. Soil samples were collected using an auger at depths of 10–20 cm at three locations in each study system and mixed to take representative samples. Soil pH and soil EC were determined by mixing soil with water at a ratio of 1: 2 w/v. The soil texture was determined using the hydrometer after the removal of organic content by H_2O_2. Organic carbon was analyzed by the chromic acid wet digestion method (Walkley and Black, 1934), and total nitrogen was extracted by macro-Kjeldahl method (Piper, 1966). Soil density was determined by collecting a volume of soil using a metal mold, pressing it into the soil at a depth of 0-10 cm, and then measuring the dry weight.

The air temperature inside the chamber and the depth of the water layer in the field were monitored during the gas collection. Soil EC, moisture, and temperature at a depth of approximately 5 cm were recorded simultaneously with a portable meter (ThermoFisher scientific instruments model WP-81 RS232).

Table 1 Crop type and nitrogen fertilization practices in rice, rice-vegetable rotation, and continuous vegetable system

Crop type	**Crop growth/ Experimental period**	**Fertilizer application rates** *kg N ha^{-1}*
Paddy rice with salinity intrusion (SRR), Freshwater paddy rice (FRR)		
- Spring crop (season 1) *(Oryza sativa L.)*	22 Feb 2016 – 20 Jun 2016	146
- Fallow time	*21 Jun 2016 – 6 Aug 2016* *5 July – 6 Aug 2016 (Turn over plowing, soil immersion into water)*	
- Autumn crop (season 2) *(Oryza sativa L.)*	7 Aug 2016 – 23 Oct 2016	184
- Fallow time	*24 Oct 2016 – 20 Feb 2017*	
Rice-vegetable rotation (RV)		
Potato (season 1) *(Solanum tuberosum L.)*	30 Dec 2015 – 14 Mar 2016	272
Watermelon (season 2) *(Citrullus lanatus Thunb.)*	16 Mar – 4 Jun 2016	134
Pear-shaped melon (season 3) *(Cucumis melo L.)*	17 May 2016 – 20 July 2016	94
Rice (season 3) *(Oryza sativa L.)*	30 July 2016 – 15 Oct 2016	158
Cabbage (season 4) *(Brassica oleracea L.)*	25 Oct 2016 – 16 Jan 2017	218
Continuous vegetable (CV)		
Potato (season 1) *(Solanum tuberosum L.)*	30 Nov 2015 – 30 Mar 2016	230
Pear-shaped melon (season 2) *(Cucumis melo L.)*	3 Apr 2016 – 4 Jun 2016	105
Watermelon (season 3) *(Citrullus lanatus Thunb.)*	21 Jun 2016 – 26 Aug 2016	130
Radish (season 4) *(Beta vulgaris L.)*	28 Sep 2016 – 25 Nov 2016	90
Cabbage (season 5) *(Brassica oleracea L.)*	28 Nov 2016 – 8 Feb 2016	150

Gas sampling and analysis

The GHG fluxes emitted from the soil were taken twice per month for a year from January 2016 to February 2017. As suggested by previous research (Yao et al., 2009, Buendia et al., 1998), gas samples were taken from static chambers from 9 am to 11 am to get the average daily emissions (to obtain a daily average flux). The static chamber with an internal dimension of 0.5m × 0.5m × 1m (length × width × height) was used to collect gas samples from rice field whereas another chamber with an internal dimension of 0.5m × 0.5m × 0.5m (width × width × height) was applied on arable land (Zhou et al., 2015). Each static chamber was installed with a fan to uniformly flow the gas concentration. Chamber bases were inserted deeply in the soil with 15cm for rice and 10cm for vegetables. The chamber was installed without the interference of crop growth. Gas samples were taken immediately right after the chamber lids were closed every 15 minutes (4 times at 0, 15, 30, and 45 minutes) in the space above the top of the chamber using 60 ml plastic syringes through a tube connected to the chamber. They were then immediately injected into 20 ml evacuated vials closed with butyl rubber septa through a three-way stopcock connected with the syringe.

The concentrations of GHGs (CO_2, CH_4 and N_2O) flux were analyzed at Agrosphere (IBG3) Institute, Juelich research Center (Forschungszentrum Juelich), Germany. The gas samples were quantified with gas chromatography using a Perkin Elmer Clarus 580 GC with a TurboMatrix 110 headspace auto-sampler fitted with an electron capture detector (for N_2O analysis) and a flame ionization detector connected to a methanizer (for CO_2 and CH_4 analysis) with two identical Elite PLOT Q mega-bore capillary columns (Perkin Elmer, Shelton, Connecticut, USA).

Fluxes for GHGs were determined from the linear or nonlinear change of concentration in a set of four samples taken over the 45 min sampling period according to Equation 1:

$$F = \rho \times h \times dC/dt \times 273/(273 + T) \quad (1)$$

Where: F is the gas ($CO_2/CH_4/N_2O$) flux (mg m^{-2} h^{-1}), ρ is the gas density at the standard state, h is the height of the chamber above the soil/water surface (m), dC/dt is the gas mixing ratio concentration (mg m^{-3} h^{-1} and T is the mean air temperature inside the chamber during sampling (°C). The sample sets were validated if the linear regression value of r^2 was greater than 0.90 to enhance the quality of the flux data.

Cumulative gas emissions were calculated from the pairs of adjacent and the time between the measurements as the following Equation 2:

$$CE = \sum (F_i + F_i+1)/2 \times 10^{-3} \times d \times 24 \times 10 \quad (2)$$

Where: CE is total emissions (kg ha^{-1}), F_i and $F_i + 1$ are the measured fluxes of two consecutive sampling days (mg m^{-2} h^{-1}), and d is the number of days between two continuous sampling days.

The global warming potential (GWP) based on the CH_4, CO_2, and N_2O emissions was used to estimate the most recent GWP contribution for a 100-year time frame without considering the climate-carbon feedbacks (IPCC, 2013) with factors of 28 for CH_4 and 265 for N_2O following Equation 3.

$$GWP\ (\text{kg } CO_2\text{- equivalents ha}^{-1}) = CE(CO_2) \times 1 + CE(CH_4) \times 28 + CE(N_2O) \times 265 \quad (3)$$

Average fluxes, cumulative gas emissions of greenhouse gases, and the other supplementary measurements with standard deviation were given from triplicate fields during evaluation.

Results and discussions

Soil parameters of measurement sites

Table 2 shows the soil physiochemical properties of RV, CV, SRR, and FRR land use types. Soil textures in the study sites varied from clay to sand. RV and CV systems has the sandy soil properties with more than 80%. Soil available of total N (0.43-0.59 g/kg), total organic C (3.16-4.64g/kg). These soil properties are known to affect CH_4 emissions in various forms, although there is no evidence on a strong coleration (Vo et al., 2017). The EC and pH show a difference among LUT systems. The EC shows highest at the SRR (5.1 dS/m), higher than other LUTs. It was reported that EC affected indirectly on N_2O emission via microbial communities (Adviento-Borbe et al., 2006).

Table 2 Soil physicochemical properties under different LUT systems in Giao Thuy district

LUT	N	Soil particles (%)			pH_{KCl}	Bulk density	EC	TN	OC
		Clay	Limon	Sand		(g/cm^3)	(dS/m)	(g/kg)	(g/kg)
RV	18	3.9	15.5	80.6	7.1±0.1	1.12±0.08	1.9 ±0.5	0.44±0.02	3.43±0.3
CV	18	2.6	14.4	83.0	7.3±0.1	1.09±0.11	3.0 ±1.0	0.43±0.04	3.16±0.3
SRR	18	35.1	11.9	53.0	7.9±0.2	1.06±0.06	5.1 ±0.6	0.59±0.06	4.64±0.2
FRR	18	32.3	15.8	51.9	7.6±0.2	1.06±0.05	3.6 ±0.1	0.57±0.02	4.27±0.4

Methane emissions

Figure 2 shows the fluctuations of methane emissions by crops. In the paddy fields (Fig. 2a), CH_4 emissions ranged from -1.53 to 54.67 mg $m^{-2}h^{-1}$ for freshwater paddy rice (FRR). The CH_4 emission in the SRR was about 2 times higher than that of FRR, and the range of -1.06 to 99.55 mg $m^{-2}h^{-1}$. The general trend of variations was that CH_4 increased during the growing period of rice but reduced suddenly when the fields were dry during harvest and transplanting time. Between two crop seasons (Jul – Aug), CH_4 emissions were as high as the spring-summer season.

In terms of seasonal variations, both rice fields had average winter-spring CH_4 emissions much higher than that of the summer-autumn, which were 19.12 compared to 10.52 mg $m^{-2}h^{-1}$ for FRR; and 30.17 compared to 16.09 mg C $m^{-2}h^{-1}$ for SRR, respectively. CH_4 emissions in the winter-spring crop were low during the first 2 months after transplanting, less than 17 mg C $m^{-2}h^{-1}$, then gradually increased in the successive period of tillering and ripening. The emissions reached the peak at the time of field drainage, before reaping and falling to the bottom at the harvesting time. The CH_4 emissions in the summer-autumn, on the other hand, are relatively stable throughout the season, then gradually decrease when water was drained to almost zero until harvesting. Significant increases of CH_4 emissions were from March to May in the winter-spring and from July to August in the summer season. The changes in CH_4 emissions in the rice fields were reported to be related to water conditions (Liang et al., 2016). Under the saturated state (during land preparation in Jul, and the growing period) the CH_4 emissions were relatively high possibly because of the emissions from soil trapping after immersion into water (Table 1). In contrast, an alternate wetting and drying practice during harvesting and transplanting resulted in nearly zero emissions. According to (Oo et al., 2018), the sudden change of water state affects the anaerobic microorganisms, resulting in a significant reduction in the amount of CH_4. Particularly, The drainage between winter-spring and summer-autumn seasons took place in a short time, so methanogen bacteria could facilitate CH_4 production immediately after transplanting (Zou et al., 2007).

The previous research findings (Gaihre et al., 2013) suggested that temperatures were also a significant driving factor in CH_4 emissions. In the rice fields, the increase in CH_4 emissions may be related to the boosting effect of temperature on the decomposition of residual biomass from the previous rice crop (Oo et al., 2018). The rise in temperature during the rainy season is also the cause of increased CH_4 emissions (Sun et al., 2013). During the fallow period between rice systems, and crop seasons, CH_4 emission was almost low, ranging from - 0.03 to 3.23 mg C $m^{-2}h^{-1}$ for FRR and from -0.02 to 21.30 mg C $m^{-2}h^{-1}$ for SRR. This can be explained by the absence of anaerobic conditions adversely affecting CH_4 production and emissions. The CH_4 emission from the rice-vegetable (RV) rotation fields ranged from 0.03 to 4.48 mg C $m^{-2}h^{-1}$ (the average rate of 1.1 mg C $m^{-2}h^{-1}$). During raining season, the emissions had an increasing trend but were insignificant, an average rate of 1.39 mg C $m^{-2}h^{-1}$) while reaching an average of 0.78 mg C $m^{-2}h^{-1}$ in the dry season. There was no significant difference in CH_4 emissions between rice and vegetable crops in the RV fields. CH_4 emissions were high during the rice growing season, especially during the flowering period, and then were gradually reduced to almost zero by the end of the rice crop. In general, the RV rotation system produced less CH_4 emission than the continuous rice crop system.

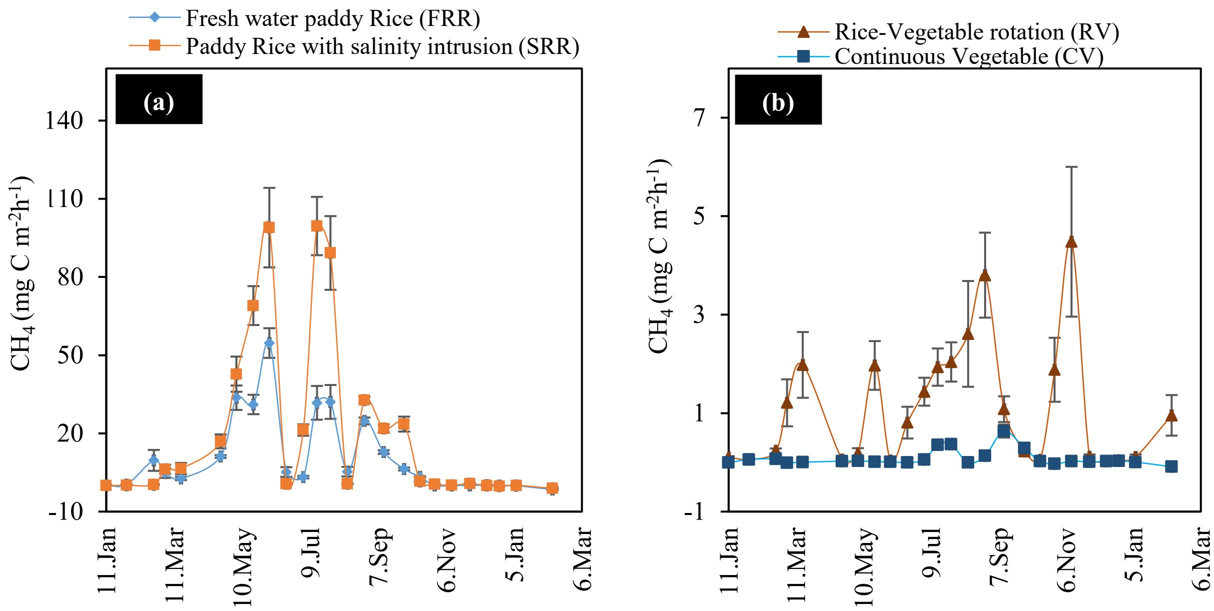

Fig. 2 CH_4 emissions from (a) freshwater paddy rice and paddy rice with salinity intrusion; and (b) rice - vegetable rotation and continuous vegetable

Cumulative methane emissions

The annual cumulative CH_4 emissions from FRR and SRR were estimated at 971.4 and 1852.5 kg C ha^{-1}, respectively (Fig. 3). The cumulative CH_4 increased rapidly in the rainy season. Comparatively, CH_4 emissions of FRR and SRR accounted for 64.4% and 51.3% in the winter-spring season; 22.4% and 18.3% in the summer-autumn crop, respectively. Cumulative CH_4 emissions were 101.7 kg C ha^{-1} with larger accumulation emissions in RV which accounted for 72.5 %. Meanwhile, cumulative CH_4 emissions in CV were relatively low, 7.8 kg C ha^{-1}, which occurred mainly in the rainy season. The cumulative CH_4 emissions of four crop systems are similar to and as a consequence of CH_4 emissions throughout the year.

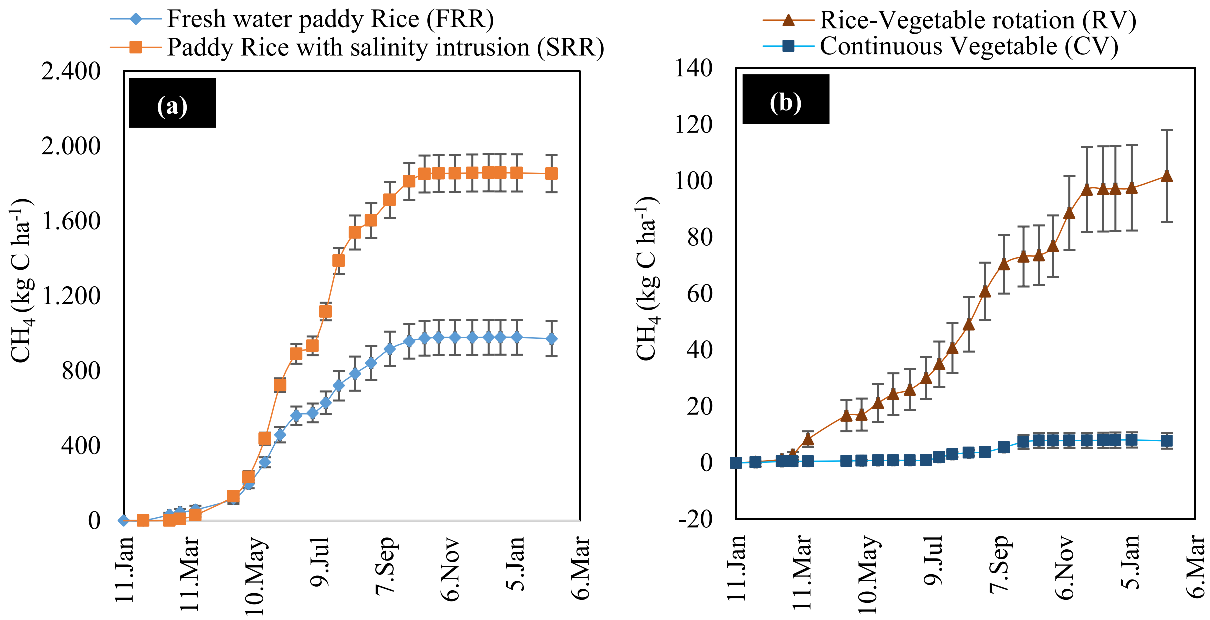

Fig. 3 Cumulative CH_4 emissions for different LUTs (mean ± std. error) from (a) freshwater paddy rice and paddy rice with salinity intrusion soils, (b) rice - vegetable rotation and continuous vegetable soils.

Nitrous oxide emission

The fluctuations of N_2O emissions from rice fields are shown in Fig. 4a. Similar to CH_4, N_2O emissions are quite different among crop types. Similar to the previous study (Ghosh et al., 2017), SRR tends to have higher N_2O emissions than freshwater rice fields. In SRR, daily fluxes of N_2O ranged from -0.0019 to 0.1411 mg N $m^{-2}h^{-1}$ (the average of 0.0375 mg N $m^{-2}h^{-1}$) while in FRR, the fluxes were -0.0015 to 0.125 mg N $m^{-2}h^{-1}$ (the average of 0.0262 mg N $m^{-2}h^{-1}$). In both rice fields, the average N_2O emissions in the summer were higher than that of the spring crop. During the winter-spring season, N_2O emissions increased immediately in FRR after transplanting and reached the peak at 0.071 mg N $m^{-2}h^{-1}$, then decreased gradually during the tillering, ripening, and harvesting time. In SRR fields, the N_2O emissions reached their highest of 0.14 mg N $m^{-2}h^{-1}$ in the harvesting period. During the summer-autumn season, N_2O emissions remained low after transplanting and increased during ripening and harvesting when water was depleted. In the summer crop, during the land preparation, N_2O was relatively high in SRR (0.07 mg N $m^{-2}h^{-1}$) but low in FRR (0.011 mg N $m^{-2}h^{-1}$). The data measured during the soil preparation in the winter-spring crop showed that N_2O emissions were quite low in both SRR and FRR.

In the vegetable fields (Fig 4b), N_2O fluxes largely ranged from 0.03 to 3.44 mg N $m^{-2}h^{-1}$, with an average flux of 0.55 mg N $m^{-2}h^{-1}$ (Figure 4b). Average N_2O emissions from vegetables were 0.66 mg N $m^{-2}h^{-1}$, three times higher than that of rice crop which was only 0.22 mg N $m^{-2}h^{-1}$. In addition, N_2O emissions from the continuous vegetable system in the rainy season were two times higher compared to the drying season, 0.93 and 0.50 mg N $m^{-2}h^{-1}$, respectively. In the rice-vegetable rotation, N_2O emissions from either raining or drying season did not show a significant difference (0.60 in raining season and 0.50 mg N $m^{-2}h^{-1}$ in drying season). Average N_2O emissions in the continuous vegetable system were 0,16 mg N $m^{-2}h^{-1}$ which was 3.5 times less than the rice-vegetable rotation system. This could be due to the differences in soil characteristics and nitrogen fertilizers in two cropping systems. N_2O emissions were found to be high on the 10^{th} day after nitrogen application and soil preparation (e.g., 21 April, 5 May, 3 June, 26 August, 27 October, 12 December for RV system and 21 April, 5 May; 12 September for CV system).

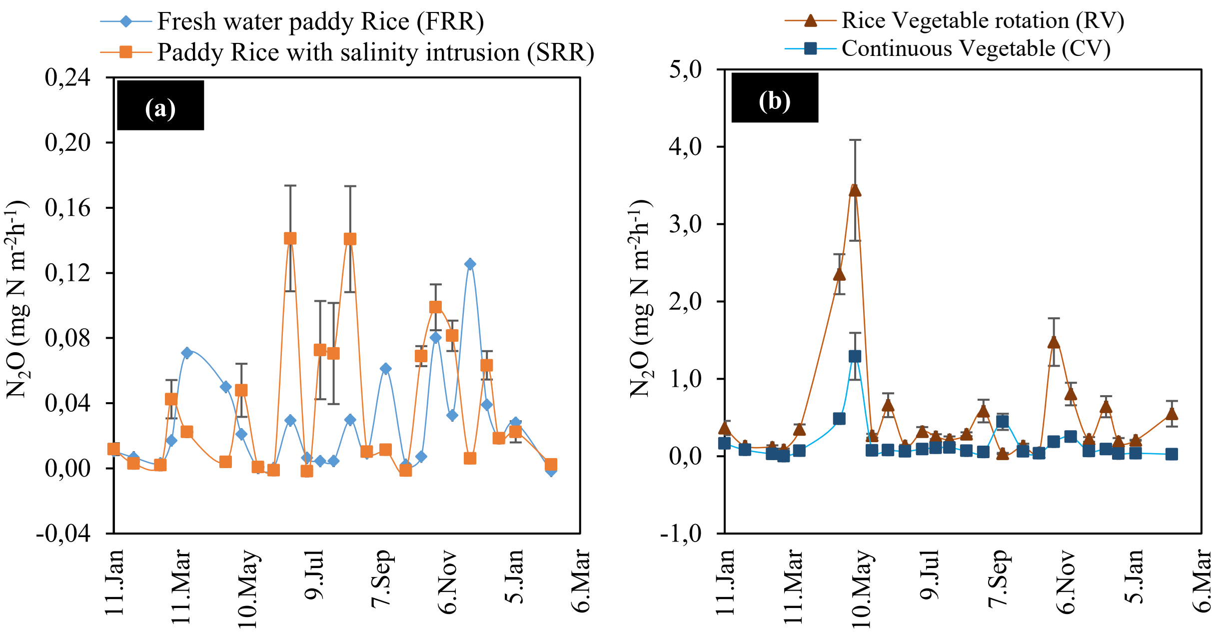

Fig. 4 N_2O emissions from (a) freshwater paddy rice and paddy rice with salinity intrusion; and (b) rice - vegetable rotation and continuous vegetable

Cumulative nitrous oxide emission

The annual cumulative N_2O emissions from FRR and SRR were 2.67 and 3.28 kg C ha^{-1}, respectively. N_2O emissions increased rapidly for SRR compared to FRR in the summer season, the rapid accumulation in summer-autumn found in both types of rice land. The amount of N_2O emissions of the RV system accumulated throughout the year increased proportionally to the time of rice cultivation. In the first 3 months of the year, N_2O emissions were relatively low, at 2.8 kg ha^{-1} due to cold temperatures. The N_2O emission increased rapidly in April and May and the following months, reaching 54.89 kg ha^{-1}. The emissions from RV were the highest among LUTs. Similar to RV, N_2O emissions in CV fields increased rapidly in April and May and then raised gradually during other months. The average emission was 15.48 kg ha^{-1}. The high cumulative N_2O obtained in RV and CV systems can be explained by the high rate of application of fertilizer (Table 1). It was reported that nitrogen fertilizer contributes to N_2O emissions (Fagodiya et al., 2017).

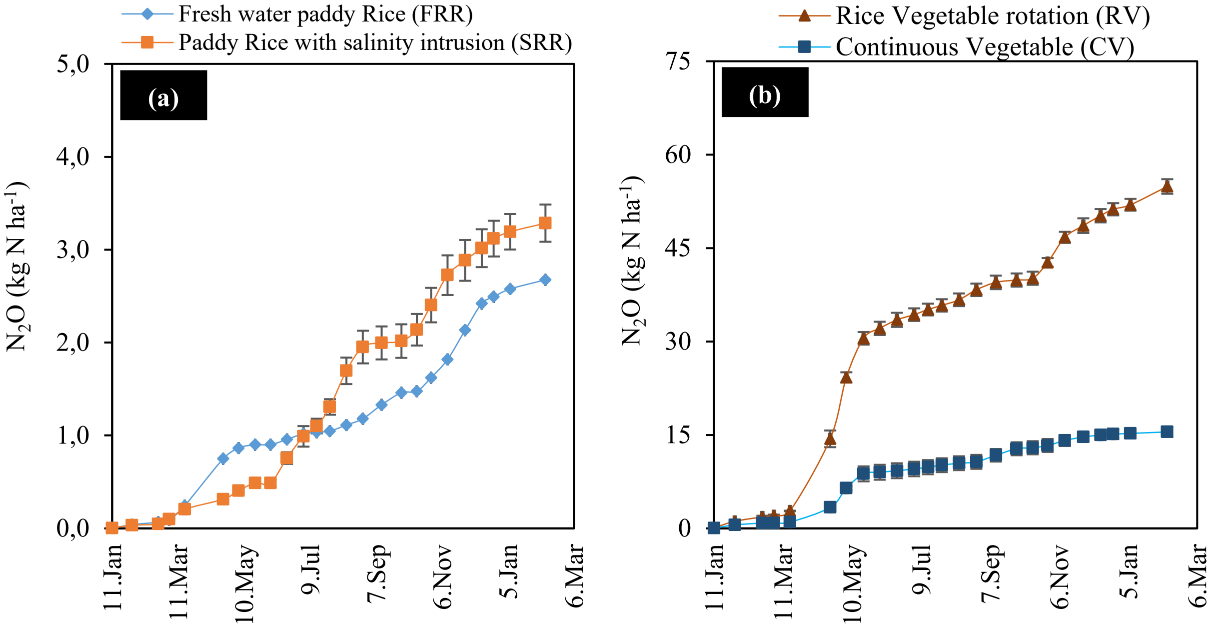

Fig. 5 Cumulative N_2O emissions for different LUTs (mean ± std. error) from (a) freshwater paddy rice and paddy rice with salinity intrusion soils, (b) rice - vegetable rotation and continuous vegetable soils

Carbon dioxide emissions

Net CO_2 fluxes from different LUTs are shown in Fig. 6. In FRR fields, CO_2 emissions fluctuated significantly throughout the year, ranging from -78.43 to 240.94 mg C $m^{-2}h^{-1}$. In the SRR, the CO_2 flux trend was similar but the range was lower, from -320.73 to 133.41 mg C $m^{-2}h^{-1}$. CO_2 emissions were low at the transplanting time, almost negative during the growing period and then raised to the highest at harvest. During the winter-spring crop, the average emissions were negative in both FRR and SRR, -46.17 and -66.22 mg C $m^{-2}h^{-1}$ while the emissions reached -61.33 and -65.94 mg C $m^{-2}h^{-1}$ during the summer-autumn season, respectively. In the fallow period, average CO_2 emissions in FRR and SRR were 8.69 and 29.77 mg C $m^{-2}h^{-1}$, respectively (Fig. 6a). CO_2 emissions from the RV system varied largely, from -177.88 to 314.62 mg C $m^{-2}h^{-1}$ with an average of 9.82 mg C $m^{-2}h^{-1}$. At the vegetable crop in the winter and spring season, CO_2 emissions ranged from -84.20 to 314.62 mg C $m^{-2}h^{-1}$ with an average of 38.39 mg C $m^{-2}h^{-1}$. During the rice crop in the rainy season, the signs of CO_2 absorption appeared when most CO_2 measurements were having negative values, the average emission rate is -95.33 mg C $m^{-2}h^{-1}$. Average CO_2 emissions in CV fields differed significantly between the dry and the rainy season (Fig. 6b). The CO_2 emissions in the dry season are 25.98 while the rainy season is 136.55 mg C $m^{-2}h^{-1}$. Daily CO_2 emissions during the dry and rainy seasons ranged from -71.94 to 164.13 mg C $m^{-2}h^{-1}$ and -94.76 to 330.40 mg C $m^{-2}h^{-1}$, respectively. In contrast to RV, CO_2 emissions in CV fields were mostly positive, with average daily emissions of 83.46 mg C $m^{-2}h^{-1}$.

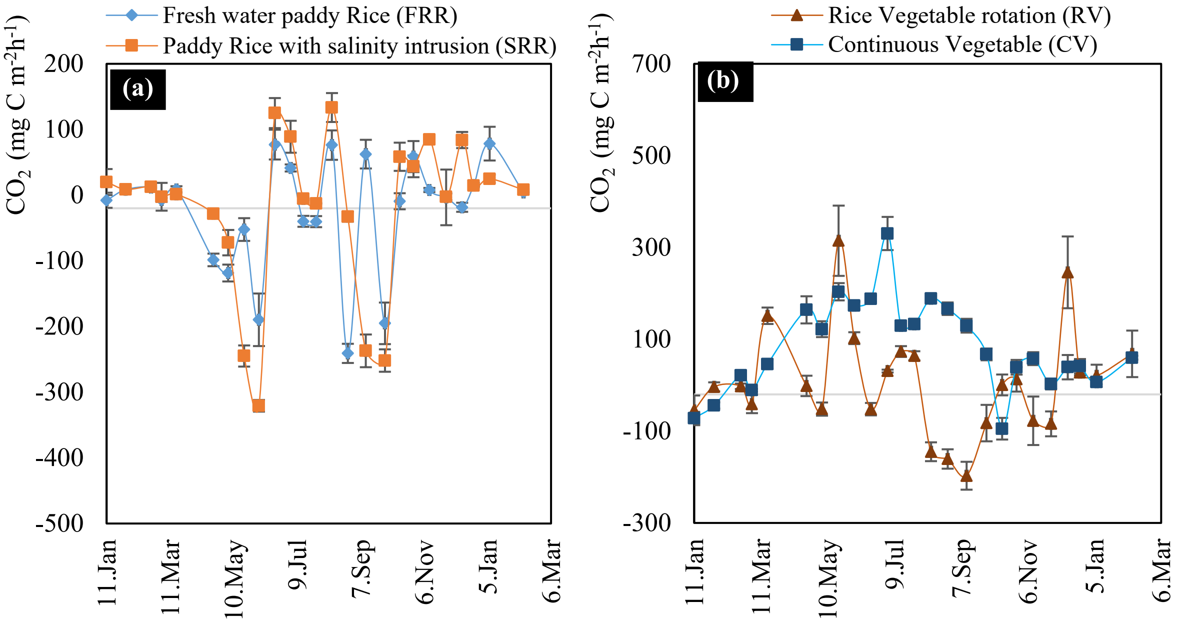

Fig. 6 CO_2 emissions from (a) freshwater paddy rice and paddy rice with salinity intrusion; and (b) rice - vegetable rotation and continuous vegetable

Cumulative carbon dioxide emission

The annual cumulative CO_2 emissions of saturated freshwater and salinity were relatively low in the first few months of the year and gradually decreased until the end of the year, reaching -2073.8 kg C ha^{-1} $year^{-1}$ in FRR and -2048.7 kg C ha^{-1} $year^{-1}$ in SRR. The results of CO_2 emission accumulation show that the FRR and SRR systems were negative while the emissions from RV, CV, and FP were positive. In contrast, annual cumulative CO_2 emissions from RV was 501.25 kg C ha^{-1} and out of which, the cumulative emission rate in the vegetable period was 2762.93 kg C ha^{-1} while this figure was -217.04 kg C ha^{-1} for the rice growing period. Accumulation had the highest amount by the middle of the year (about 2000 kg C ha^{-1}) then gradually decreased until the end of the year.

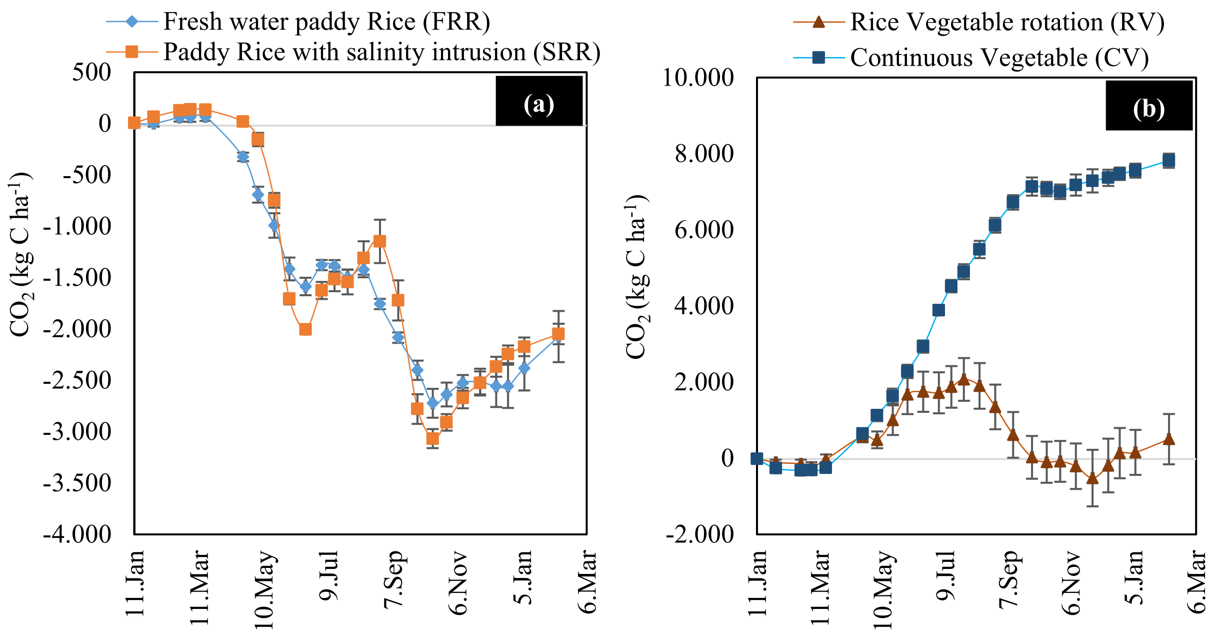

Fig. 7 Cumulative CO_2 emissions for different LUTs (mean ± std. error) from (a) freshwater paddy rice and paddy rice with salinity intrusion soils, (b) rice - vegetable rotation and continuous vegetable soils.

Global Warming Potential

The final global warming potential was calculated based on cumulative CO_2-C, CH_4-C, and N_2O-N for the FRR, SRR, RV, and CV crops systems (Table 3). The GWP of the GHG was the lowest in CV with continuous vegetables and highest in SRR with salinity intrusion rice. The total GWP of CV was 2,658 and SRR obtained 17,177 kg CO_2-eq $ha^{-1}y^{-1}$. The main contribution to the difference in net GWP between two crop types was the anaerobic conditions and electric conductivity (Table 1). The FRR and RV revealed a similar total GWP of 8389.3 and 8133.6 kg CO_2-eq $ha^{-1}y^{-1}$. It is interesting that in SRR and FRR crop systems, the cumulative CO_2 emissions were negative which may contribute to the carbon sequestration due to microorganism activities. Dendooven et al. (2012) indicated that the emission of N_2O contributed most to the GWP of the GHG, while the reduction in GWP of the GHG due to the oxidation of CH_4 was small (Dendooven et al., 2012). However, this study shows interesting data on high methane emission with the saturated salinity intrusion soil.

Table 3 Global warming potential of different crop systems

Systems	CO_2-C cumulated	CH_4-C cumulated	N_2O-N cumulated	CO_2-C GWP	CH_4 GWP	N_2O GWP	Total (GWP) CO_2-eq (kg ha^{-1} y^{-1})
FRR	-2073.8	971.4	2.67	-1805.5	9890.9	303.88	8389.3
SRR	-2048.7	1852.5	3.28	-2058.2	18862.2	373.15	17177.2
RV	501.2	101.7	54.89	863.7	1035.5	6234.41	8133.6
CV	7815.4	7.78	15.49	820	79.2	1758.82	2658.1

Conclusions

Greenhouse gases (CH_4, N_2O, CO_2) fluxes in agricultural soils varied in both the emissions amount and the rates of cumulative emissions. The CH_4 emissions were the highest at the paddy rice with salinity intrusion (SRR), then freshwater rice paddy (FRR), rice-vegetable rotation (RV), and continuous vegetable soils. The variance of CH_4 emissions rates was due to the anaerobic decomposition of organic matter by microorganisms. The N_2O emissions are quite different between crop types where SRR tends to have higher N_2O emissions than freshwater rice fields. Average N_2O emissions from vegetables were three times higher than that of rice crop which was only 0.22 mg N $m^{-2}h^{-1}$. In addition, N_2O emissions from the continuous vegetable system in the rainy season were two times higher than in the drying season. The CO_2 emissions fluctuated largely throughout the year. In FRR fields, it ranges from -78.43 to 240.94 mg C $m^{-2}h^{-1}$ and on the other hand, it was lower in SRR from -320.73 to 133.41 mg C $m^{-2}h^{-1}$. CO_2 emissions were low at the transplanting time, almost negative during the growing period, and raised to the highest at harvest. Average CO_2 emissions in CV fields differed significantly between the dry and the rainy season. The CO_2 emissions in the dry season are 25.98, while the rainy season is 136.55 mg C $m^{-2}h^{-1}$. Daily CO_2 emissions during the dry and rainy seasons ranged from -71.94 to 164.13 mg C $m^{-2}h^{-1}$ and -94.76 to 330.40 mg C$m^{-2}h^{-1}$, respectively. In contrast to RV, CO_2 emissions in CV fields were mostly positive, with average daily emissions of 83.46 mg C $m^{-2}h^{-1}$. The global warming potential was the highest in the SRR crop system, nearly 20 times higher than others. It is recommended to adjust the crop calendar to avoid salinity intrusion in the rice field and promote other crop systems in terms of greenhouse gas reduction.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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