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Effect of combine application of organic manure and inorganic fertilizer on methane and nitrous oxide emissions from a tropical flooded soil planted to rice

Suvendu Das *, Tapan K. Adhya

Laboratory of Soil Microbiology, Division of Crop Production, Central Rice Research Institute, Cuttack-753006, Orissa, India

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ABSTRACT

Methane and nitrous oxide emissions, their global warming potential, carbon efficiency ratio and related biogeochemical properties of a tropical soil planted to rice were investigated under different N management [i.e. urea-N (120 kg N ha^{-1}), rice straw (RS) (30 kg N ha^{-1}) + urea-N (90 kg N ha^{-1}), compost (C) (30 kg N ha^{-1}) + urea-N (90 kg N ha^{-1}) and poultry manure (PM) (30 kg N ha^{-1}) + urea-N (90 kg N ha^{-1})]. CH_4 fluxes were increased by 82.7%, 65.1%, 63.4% and 31.9% in RS + urea-N, C + urea-N, PM + urea-N and urea-N, respectively whereas percentage increase in cumulative N_2O emission was 390.6, 371.8, 315.6, and 253.1 in PM + urea-N, urea-N, C + urea-N and RS + urea-N, respectively over control (no fertilizer amendment). However, increase of GWPs in different manure + urea-N over that of control were 85.5%, 69.2%, 68.8% and 37.6% in RS + urea-N, C + urea-N, PM + urea-N and urea-N, respectively. Microbial biomass carbon (MBC), readily mineralizable carbon (RMC) and fluorescence diacetate (FDA) hydrolysis activity were significantly affected by integrated N-management and followed the order of C + urea-N > PM + urea-N > RS + urea-N > urea-N > control. With considerably high microbial biomass C and microbial activity, high C efficiency ratio, high yield and low greenhouse gas intensity, C + urea-N could be a better option to mitigate CH_4 and N_2O emissions and to maintain soil biological quality and yield in tropical paddy.

1. Introduction

Agricultural soil contributes towards the emissions of methane (CH_4) and nitrous oxide (N_2O), the two most important greenhouse gases responsible for global warming. The contribution of agriculture *per se* to present anthropogenic emissions is estimated to be ~ 70% (Mosier et al., 2004). Both the gases are estimated to be collectively responsible for about 20% of the anticipated global warming (Smith et al., 2007). Globally, agricultural CH_4 and N_2O emissions have increased by nearly 17% from 1990 to 2005 (IPCC, 2007), and agricultural N_2O emissions are projected to increase by 35–60% up to 2030 due to increased chemical and manure N inputs (FAO, 2003).

Rice paddies have been identified as a major source of atmospheric CH_4 and N_2O (Das et al., 2011a). The global CH_4 emission rate from paddy fields was estimated to be 20–40 Tg $year^{-1}$ (Yan et al., 2009) while N_2O emission was much lower, as the total N_2O emission from overall cultivated area was estimated to be 1.7–4.8 Tg N_2O–N yr^{-1} (IPCC, 2007; Yao et al., 2010). Knowledge of how agricultural management influences sources and sinks of CH_4 and N_2O relative to crop yields is important for understanding potential anthropogenic impacts on climate forcing (Mosier et al., 2004; Uprety et al., 2012). One of the key factors influencing production and consumption of CH_4 and N_2O is fertilization (Phillips et al., 2009). The use of chemical fertilizers with organic manure has been widely recommended for sustaining agricultural production in Asia and Africa, with their degraded soil fertility and quality (Ge et al., 2010; Majumder et al., 2008). Combination of chemical N fertilizer (urea) and compost is often used by the Indian farmers to improve soil fertility as well as to get better yield (Nayak et al., 2007; Uprety et al., 2012). It is also a common practice to decompose the rice straw during the field preparation for sowing. Organic amendment, besides its nutrient values, can affect soil organic C pool (Majumder et al., 2008), soil nutrients and microbial activities (Ge et al., 2010) which are some of the controlling factors in the emissions of CH_4 and N_2O to the atmosphere. Inorganic fertilizer enhanced soil porosity by increasing regular and irregular pores and caused a priming effect of native soil organic matter (Tiquia et al., 2002) ultimately affecting CH_4 and N_2O emissions (Ge et al., 2010). There were reports that organic amendment stimulates CH_4 emission (Zou et al., 2005), however reports of N_2O emission were contradictory (Chirinda et al., 2010; Yao et al., 2010; Zou et al., 2005). Reports on the application of urea on N_2O and CH_4 effluxes from flooded rice paddies are also contradictory (Lindau et al., 1990, 1991; Zou et al., 2005). The application of a balanced amount of manures and fertilizer could increase soil microbial biomass and activities (Kanchikerimath and Singh, 2001; Tu et al., 2006) which

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* Corresponding author at: Department of Earth Sciences, National Cheng Kung University, Tainan 70101, Taiwan. Tel.: +886 6 2757575x65430 314; fax: +886 6 2740285.
E-mail address: suvendu.bls@gmail.com (S. Das).

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seemed to be a practical and effective way to improve soil fertility, enhance yield and mitigate GHG emission (Meng et al., 2005).

The present work aimed (1) to observe the effects of combine application of organic manure and urea-N on CH_4 and N_2O emissions and related biochemical parameters, (2) to examine which practice is a potential for mitigating the global warming potentials of CH_4 and N_2O emissions from flooded rice paddies of tropical origin without scarifying yield and soil biological quality.

2. Materials and methods

2.1. Site description

The field experiment was conducted at Central Rice Research Institute (CRRI), Cuttack, India (85° 55′ E, 20° 25′ N; elevated 24 m above the MSL) during the dry season (January–May). Mean maximum and minimum temperatures from January to May are 33.13 °C and 21.46 °C respectively, and the mean evaporation rate per day from January to May was 4.41 mm day^{-1}. The soil of the farm area has been developed from the deltaic sediments of the Mahanadi River in recent times. The soil was an Aeric Endoaquept with sandy clay loam texture (25.9% clay, 21.6% silt and 52.5% sand), bulk density 1.40, percolation rate < 10 mm day^{-1}, pH (1:2.5:: soil: H_2O) 6.16, cation exchange capacity 15 C mol (p^+) kg^{-1}, electrical conductivity 0.5 dS m^{-1}, total C 6.6 g kg^{-1}, total N 0.8 g kg^{-1} and exchangeable K 120 kg ha^{-1}.

2.2. Experimental design

The field was ploughed thoroughly and flooded 2–3 days before transplanting for puddling and leveling. Rice plants (25-day seedlings of *cv.* IR 36) were transplanted at a spacing of 20 cm × 10 cm with two seedlings per hill in the field plots (5 m × 5 m) well separated by levees. The experiment was laid out in a randomized block design with three replicates each. There were five treatments, *viz.* (i) control (without fertilizer amendment), (ii) Urea-N (120 kg N ha^{-1}), (iii) rice straw (RS) (30 kg N.ha^{-1}) + urea-N (90 kg N ha^{-1}), (iv) compost (C) (30 kg N ha^{-1}) + urea-N (90 kg N ha^{-1}), and (v) poultry manure (PM) (30 kg N ha^{-1}) + urea-N (90 kg N ha^{-1}). All the field plots remained continuously flooded to a water depth of 10 ± 5 cm during the entire period of crop growth and were drained 15 days before harvest.

2.3. Fertilizers and organic manure application

In urea-N treatment, urea-N (120 kg ha^{-1}) was applied to each replicated plot in three splits with 30, 45 and 45 kg N ha^{-1} at 4, 34 and 62 days after transplanting (DAT) of rice. For other treatment plots, the organic manures were incorporated 15 days before the transplanting to provide (30 kg N ha^{-1}) and were superimposed with urea-N (90 kg ha^{-1}) in two splits at 34 and 62 DAT. Potassium (60 kg K_2O ha^{-1}) was applied as muriate of potash in two splits with 2/3 of the fertilizer being applied as basal and the remaining 1/3 at the panicle initiation stage (62 DAT). Phosphorus (60 kg P_2O_5 ha^{-1}) as single superphosphate (SSP) was applied uniformly to all the field plots as basal.

2.4. CH_4 and N_2O estimations

Methane and N_2O and emissions from rice field plots were monitored using manual closed chamber method (Das et al., 2011a). Samplings for CH_4 and N_2O fluxes measurement were done from all the replicated plots in the morning (09:00–09:30) and afternoon (15:00–15:30) and the average of morning and afternoon fluxes was used as the flux for the day. The gas sampling was done on 2, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 58, 63, 68, 73, 78, 83, 90, 95 and 99 days after transplanting (DAT). Aluminum base plate (57 cm × 37 cm × 10 cm, length × width × height) with a channel to accommodate the Perspex chamber and water to provide air-tight condition was permanently fixed in the field soil at the measurement site throughout the cropping season. Six hills were enclosed inside the aluminum base. For measuring CH_4 and N_2O emissions, Perspex chamber (53 cm × 33 cm × 37 cm/53 cm × 33 cm × 71 cm, length × width × height; according to the plant height) was placed in the grooves of the aluminum base to cover the rice hills enclosed within the aluminum base. The air inside the chamber was isolated from outside atmosphere and the system was airtight. Different heights of the Perspex chamber were used to accommodate the chamber with the changes in rice plant height throughout the growing reason and to minimize the dilution of N_2O by atmospheric N_2. A battery-operated air circulation pump with air displacement of 1.51 min^{-1} (M/s Aerovironment Inc., Monrovia, CA, USA), connected to polyethylene tubing, was used to mix the air inside the chamber and draw the air samples into Tedlar® air-sampling bags (M/s Aerovironment Inc.) at fixed intervals of 0,15, and 30 min. The air samples from the sampling bags were analyzed for CH_4 and N_2O.

CH_4 concentration in the air samples collected from the crop canopy was analyzed by gas chromatography in a Varian 3600 gas chromatograph (M/s Varian Instruments Inc., USA) equipped with flame ionization detector (FID) and Porapak N column (2 m length, 1/8 in. OD, 80/100 mesh, stainless steel column). The injector, column and detector were maintained at 80, 70 and 150 °C, respectively. The carrier gas (nitrogen) flow was maintained at 30 ml min^{-1}. The gas chromatograph was calibrated before and after each set of measurements using 5.38, 9.03 and 10.8 μl CH_4 l^{-1} in N_2 (Scotty1 II analyzed gases, M/s Altech associates Inc., USA) as a primary standard and 1.95 μl l^{-1} in air as a secondary standard to provide a standard curve linear over the concentration range used. Under these conditions, the retention time of CH_4 was 0.53 min and the minimum detectable limit was 0.5 μl l^{-1}.

N_2O concentration in the air samples collected in the Tedlar1 sampling bags was analyzed in a PerkinElmer ASXL gas chromatograph (M/s PerkinElmer, USA) equipped with ^{63}Ni electron capture detector (ECD) and a Porapak Q column (2 m length, 1/8 in. OD, 80/100 mesh, stainless steel column). The injector, column and detector were maintained at 80, 60 and 350 °C, respectively. The carrier gas (nitrogen) flow was maintained at 20 ml min^{-1}. The gas chromatograph was calibrated before and after each set of measurements using 100 ppb N_2O in N_2 (Scotty1 II analyzed gases, M/s Altech Associates Inc., USA) as a primary standard and 316 ppb N_2O in N_2 (National Physical Laboratory, New Delhi) as a secondary standard. Under these conditions, the retention time of N_2O was 2.20 min and the minimum detectable limit was 100 ppb.

Fluxes of CH_4 and N_2O were calculated by successive linear interpolation of average emission on the sampling days assuming that emission followed a linear trend during the periods when no sampling was done (Das et al., 2011a). Cumulative CH_4 and N_2O emissions for the entire cropping period were computed by plotting the flux values against the days of sampling, calculating the area covered under the plot of such relationship and expressed as kg CH_4 or N_2O-N ha^{-1}.

2.5. Integrated evaluation of greenhouse gas emissions

Integrated evaluation of GHG emissions expressed as global warming potential (GWP) was computed using the IPCC factors for calculating the combined GWPs for 100 years (GWP = 25.0 × CH_4 + 298 × N_2O kg CO_2 equivalent ha^{-1}) from CH_4 and N_2O efflux values under different treatments (IPCC, 2007). GWP in terms of grain yield

Table 1
Carbon content, nitrogen content and C:N ratio of the added manure.

Manure added	Total organic carbon[a] (%)	Total nitrogen content[a] (%)	C:N ratio
Rice straw	29.93 ± 2.03	0.41 ± 0.07	73.00:1
Compost	10.88 ± 0.77	1.03 ± 0.11	10.56:1
Poultry manure	9.48 ± 0.53	1.43 ± 0.14	6.62:1

[a] Average of three replicate ± Standard Deviation.