Agriculture, Ecosystems and Environment 129 (2009) 228–237

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Methane and nitrous oxide emissions from an integrated rainfed rice–fish farming system of Eastern India

A. Datta [a,b], D.R. Nayak [a], D.P. Sinhababu [a], T.K. Adhya [a,*]

[a] Division of Crop Production, Central Rice Research Institute, Cuttack 753006, Orissa, India
[b] Global Change Centre, National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi 110012, India

ARTICLE INFO

Article history:
Received 15 March 2008
Received in revised form 31 August 2008
Accepted 5 September 2008
Available online 17 October 2008

Keywords:
Methane emission
Nitrous oxide emission
Rice–fish farming system
Sustainable agriculture
Global warming potential
C-credit compliance

ABSTRACT

Integration of fish stocking with rice (*Oryza sativa* L.) cultivation promises an ecologically sound and environmentally viable management of flooded ecosystem. Rice agriculture contributes to the emission of greenhouse gases CH_4 and N_2O, but little is known on the effect of fish rearing in fields planted to rice on the emission of these two greenhouse gases. In a field study, CH_4 and N_2O fluxes were measured from a sub-humid tropical rice field of Cuttack, eastern India, as affected by integrated rice–fish farming under rainfed lowland conditions. Three Indian major carps, *Catla catla* H., *Labeo rohita* H. and *Cirrhinus mrigala* H., and *Puntius gonionotus* B. were stocked in rice fields planted to two rice cultivars in a split-plot design with no fish and fish as the main treatments and two rice varieties as sub-treatments with three replicates each. Fish rearing increased CH_4 emission from field plots planted to both the rice cultivars with 112% increase in CH_4 emission in *cv.* Varshadhan and 74% in case of *cv.* Durga. On the contrary, fish stocking reduced N_2O emission from field plots planted to both the rice varieties. Movement of fish and associated bioturbation coupled with higher dissolved organic-C and CH_4 contents, and lower dissolved oxygen could be the reasons for release of larger quantities of CH_4 from rice + fish plots, while higher dissolved oxygen content might have influenced release of more N_2O from the rice alone treatment. The total greenhouse gas emission, expressed as CO_2 equivalent global warming potential (GWP), was considerably higher from rice + fish plots with CH_4 contributing a larger share (91%) as compared to rice alone plots (78–81%). On the contrary, N_2O had a comparatively lesser contribution with 19–22% share in rice alone plots that was further reduced to 9% in rice + fish plots. However, considering the profit-loss analysis based on the market price of the produce, rice–fish system provided a net profit of \$453.36 ha^{-1} over rice alone system in spite of higher carbon credit compliance of a rice–fish ecosystem due to larger cumulative GWP.

1. Introduction

Flooded fields planted to rice (*Oryza sativa* L.) are important anthropogenic sources of atmospheric methane (CH_4) and nitrous oxide (N_2O), two potent greenhouse gases with relative global warming potentials of 25 and 298 times that of carbon dioxide (CO_2) over a time horizon of 100 years (IPCC, 2007). Biogenic CH_4 is produced in the anoxic environments of submerged soils and sediments including rice paddies during anaerobic degradation of organic-C compounds and enters the atmosphere at or near the earth's surface after escaping from the methanogenic habitats (Conrad, 1996). Rice paddies contribute approximately 10–13% to the global CH_4 emission (Crutzen and Lelieveld, 2001). The most crucial process for CH_4 emission from flooded paddy is its production which is influenced by a number of soil processes as well as common cultivation practices including rice variety (Satpathy et al., 1998) grown, while the plant-mediated transport of produced CH_4 is important for its release to the atmosphere (Wassmann and Aulakh, 2000). On the contrary, while earlier reports indicated negligible N_2O emission from flooded paddy fields (Smith et al., 1982), some of the later studies suggest that rice cultivation might be a significant anthropogenic source of N_2O (Cai et al., 1997). N_2O emission from paddy fields is affected by soil processes including nitrification–denitrification, climate and soil type and most importantly, form and mode of application of fertilizer-N (Cai et al., 1997; Akiyama et al., 2005). Such variability in the production and emission of CH_4 and N_2O is further compounded with a large degree of spatial and temporal

* Corresponding author. Tel.: +91 671 2367777x312; fax: +91 671 2367663.
E-mail address: adhyas@yahoo.com (T.K. Adhya).

0167-8809/\$ – see front matter
doi:10.1016/j.agee.2008.09.003

(interannual and interseasonal) variations. Thus, there is large uncertainty in the estimated values for total CH_4 and N_2O emission from rice paddies of the world. While global estimates on CH_4 emission from rice paddies show an average of 20–150 Tg $year^{-1}$ (Mosier et al., 1998), estimated whole-year background emission of N_2O from flooded paddy amounts to ~0.28 Tg $year^{-1}$ (Akiyama et al., 2005). In order to increase the accuracy in the estimation of CH_4 and N_2O emission from rice cultivation and to predict the future CH_4 and N_2O emission as well as to develop desired mitigation options, intensive monitoring of CH_4 and N_2O emission from rice paddy is highly imperative. Rice cultivation contributes a large part to the tropical food production, especially in Asia covering about 154 million ha with more than 65% area located in south and south-east Asia. Projected increase in rice production during the coming decades (Maclean et al., 2002) is anticipated to result in a further increase in CH_4 and N_2O fluxes to the atmosphere due to intensification of the prevalent cultivation practices.

Rice–fish systems co-evolved alongside wet rice cultivation in southeast Asia over 6000 years ago (Ruddle, 1982) and are a sustainable form of agriculture (Heckman, 1979; Kurihara, 1989) providing invaluable protein, especially for subsistence farmers managing marginal farming systems of rainfed lowland ecology. Traditional rainfed lowlands, flood-prone (deep water) and irrigated rice agro-ecosystems lend themselves for fish culture when the whole rice field has a water depth of 0.3–1.0 m. Rice–fish farming has been recorded in tropical and subtropical Asia over the past 150 years. Its combined production has been propagated most intensely over the past 15–20 years, coinciding with the international emphasis on food production and nutritional security for a rapidly growing human population (Fernando, 1993). While a total of ~1.08 million ha currently being used for rice–fish farming, there is a potential of 10.2 million ha of rice area being brought under this system of cultivation (Lightfoot et al., 1992). Transformation of wetlands and rice fields for rice–fish production tends to directly benefit food production and income, as well as farm integration (Lightfoot et al., 1993). A rich variety of direct and mainly indirect beneficial effects emanate from the interactions between rice and fish (Koohafkan and Furtado, 2004).

Rice–fish farming systems are globally important in terms of three environmental issues, *viz.* climate change, shared water and biodiversity. CH_4 and N_2O are the major greenhouse gases emitted from rice fields, but the impact of integration of fish in rice cultivation on the emission of these two greenhouse gases are not known. As a result, it is not easy either to apply appropriate mitigation measures or to design trade-offs between mitigation measures and rice and fish production (Ranganathan et al., 1995). One of the possibilities is the application of global environmental subsidies (carbon credit) where national developing economies are unable to allocate them the desired priority. There are also innovative agricultural systems with a variety of local designs adapted to, *viz.* cultural attributes, appropriate rice and fish species for husbandry, different kinds of water resource availability, timing and drainage, natural and artificial nutrient inputs for growth, the biological and chemical control of pests and diseases, and edaphic conditions. It is essential to understand the impact of such agricultural interventions on the emission of CH_4 and N_2O from this economically important farming system.

Oxygen deficiency and reducing conditions are characteristics of flooded rice soils (Ponnamperuma, 1972; Liesack et al., 2000). Such reducing conditions often provide a congenial environment for CH_4 production (Kruger et al., 2001). It was previously considered that fish might aerate the paddy soil by burrowing into the soil for searching food (Lightfoot et al., 1992a). This would prevent a drop in the redox potential and lower CH_4 emission and by default would increase N_2O emission. However, in a field experiment, Frei et al. (2007) reported an increase in CH_4 emission in rice–fish treatment that resulted from the bioturbation effect created by the movement of fish. Our objectives in the present study were: (1) to investigate the effect of fish growing on CH_4 and N_2O emission from an integrated rice–fish farming system of eastern India under rainfed lowland conditions; (2) to scrutinize the dynamics of total organic carbon (C_{TOC}) and total N (N_{TOTAL}) contents of the soil and the changes in select physico-chemical properties of soil and water in relation to CH_4 and N_2O emission in an integrated rainfed rice–fish farming system; and (3) to assess the environmental impact of the rice–fish system *vis-á-vis* its economic benefit for the farmers and contribution to the food and nutritional security in rainfed lowland agro-ecologies.

2. Materials and methods

2.1. Field experiment

A field experiment was carried out during the wet cropping season (June–December) of 2005 at the experimental farm of the Central Rice Research Institute (CRRI), Cuttack, India (85°55′E, 20°25′N; elevation 24 m). Annual precipitation is ~1500 mm $year^{-1}$, of which ~75% occurs during June–September. Mean seasonal maximum and minimum temperatures during the wet season of 2005 was 39.2 and 22.5 °C, respectively and the mean seasonal ambient temperature was 27.7 °C. The soil was an Aeric Endoaquept with sandy clay loam texture (25.9% clay, 21.6% silt, 52.5% sand), bulk density 1.40 Mg m^{-3} and percolation rate < 10 mm day^{-1}. Soil collected from the plough layer (0–15 cm) had pH (H_2O) 6.16, cation exchange capacity 15 mEquiv. 100 g^{-1}, electrical conductivity 0.5 dS m^{-1}, total C 0.66% and total N 0.08%, exchangeable K 120 kg ha^{-1}.

The field plot had a natural gradient of 0.08 cm m^{-1} from west to east and a refuge pond of 10.0 m width and 1.75 m depth was constructed at the eastern end of the field for gathering the field water during the post-monsoonal period and also acted as a sanctuary for the fish. A peripheral trench (3.0 m width and 1.0 m depth) was excavated around the rice growing area which was blocked at the western end and connected to the mainland for easy access to the rice plot. The field was prepared by raising the levees and providing trenches for fish movement. The field was ploughed several times, larger clods broken and leveled on the third week of May 2005. The field was divided in 10 m × 10 m plots. Two promising lowland rice cultivars, *cv.* Varshadhan and Durga were dry-seeded with 80 kg seed ha^{-1} in rows 20 cm apart on May 31, 2005. A fertilizer schedule of 40 kg N ha^{-1} as urea and 20 kg each of P and K ha^{-1} as P_2O_5 (as single superphosphate) and K_2O (as muriate of potash) was applied at the time of sowing and covered with a thin layer of soil. The weeds germinated along with rice and remained in the field till accumulation of rain water. Subsequently, most of the terrestrial weeds perished with the increase in the water level and the aquatic weed population gradually built up. After sufficient water accumulation in the refuge system and in the field, fish fingerlings of 8–10 cm size and average weight of 8 ± 2 g, were released during the first week of August at a stocking density of 6000 fingerlings ha^{-1}. The fish species stocked belonged to three Indian major carps, *viz.* catla (*Catla catla* H.), rohu (*Labeo rohita* H.) and mrigal (*Cirrhinus mrigala* H.) and *Puntius gonionotus* B. at a ratio of 30, 25, 30 and 15 (on a percentage basis), respectively. Fish stock was regularly fed with a mixture of oil cake and rice bran or polish (1:1) at 2% of total biomass applied daily in feeding trays in the refuge tank. No plant protection or weed control measures were undertaken.

The experiment was laid out in a split-plot design with the two treatments, no fish and fish as the main treatments and two rice varieties as sub-treatments with three replications each.