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Research Paper

Methane and nitrous oxide emissions from conventional and modified rice cultivation systems in South India

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ABSTRACT

Rice (*Oryza sativa* L.) production is facing major challenges, including scarcity of irrigation water and ongoing climate change. Modifications of the current cropping techniques could increase yield, save water, and mitigate greenhouse gas emission. We investigated the effect of planting methods (young seedlings, wide spacing with alternate wetting and drying irrigation [YW-AWD], old seedlings, narrow spacing with continuous flooding [ON-CF], and in-between the two planting methods [IB-AWD]) and rice varieties on methane (CH_4) and (N_2O) emissions during two crop seasons. The results show that CH_4 emission, averaged over rice varieties, reduced for YW-AWD by 41% and 24%, compared with ON-CF, while the reduction in emission for the IB-AWD method was 48% and 26% in summer (dry) and monsoon (wet) season, respectively. However, an increase in N_2O emission was observed for YW-AWD and IB-AWD methods in both seasons. There was no significant difference in CH_4 and N_2O emissions between the tested varieties. The total water saving under YW-AWD and IB-AWD was 47.5% and 49.3% in summer, and 79.4% and 79.8% in monsoon season, respectively, compared with ON-CF. The grain yields of YW-AWD and IB-AWD were comparable with the yield of ON-CF in both seasons. The CO_2-eq emission and yield-scaled CO_2-eq emission from YW-AWD and IB-AWD were significantly lower compared with ON−CF due to low CH_4 emission, while maintaining similar rice yields. This study showed that the YW-AWD and IB-AWD methods are effective in reducing CO_2-eq emission and saving irrigation water, while maintaining the rice yield.

1. Introduction

Agriculture is estimated to account for 10%–20% of anthropogenic greenhouse gas (GHG) emissions worldwide (Smith et al., 2008); in 2005, it accounted for 50% and 60% of the total anthropogenic methane (CH_4) and nitrous oxide (N_2O) emissions, respectively. Rice paddies are considered one of the most important sources of CH_4 and N_2O emissions, which have attracted considerable attention due to their contribution to global warming (Harris et al., 1985; Bouwman, 1990). In India, paddy rice cultivation occupies about 44 million ha, the largest rice producing area in Asia, and accounts for 20% of the total rice production worldwide. India would need to produce up to 130 million t of milled rice by 2030 to meet the growing demands, in contrast with 92 million t in 2005 (Gujja and Thiyagarajan, 2009). To ensure food security for the growing population, expansion of rice-cropped area and continuous intensification of rice cultivation would likely increase greenhouse gas emissions. Data on trade-offs between rice yield increase and reduction in greenhouse gas emissions are urgently needed for innovation in cropping techniques.

Modification of current cropping technique might be a way to reduce greenhouse gas emissions from rice soil. In this respect, a system of rice intensification has been introduced as an efficient, resource saving, and productive strategy to practice rice farming. It involves reduced water application, organic amendments, and transplanting

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young single seedling per hill with wide spacing. Studies have reported a positive effect on yield (Gujja and Thiyagarajan, 2009; Jain et al., 2014) and reduction in CH_4 emission under this method (Fazli and Man, 2014). However, some other studies have found no significant effect on grain yield or even a negative effect, with the system of rice intensification (Chapagain et al., 2011; Jain et al., 2014). This might be due to a reduction in the initial population size while transplanting a single seedling per hill. Therefore, another cultivation method was introduced, which was in-between the conventional practice and the system of rice intensification. In this cultivation system, 2–3 seedlings should be planted per hill with wide spacing, to increase the initial population size at transplanting.

One practice that has been shown to reduce the water use in rice systems is alternate wetting and drying irrigation (AWD) (Linquist et al., 2014; Lampayan et al., 2015). It is an approach to increase rice productivity through proper management of resources. This practice is being promoted by the International Rice Research Institute (IRRI) and the national research and extension programs in Bangladesh, India, and other parts of the world, as a water-saving irrigation practice. In Bangladesh, on-farm trials indicated that AWD reduced the irrigation input by 13%–38%, while increasing the yield by 0.4–1.0 t ha^{-1} (Lampayan et al., 2015). Various studies have also reported that AWD irrigation can save irrigation water without losses in rice grain yield (Yao et al., 2012; Belder et al., 2004), while reducing CH_4 emission from the rice soil (Yagi et al., 1996; Ly et al., 2013). However, considerable amounts of N_2O emission could occur in rice fields because of AWD (Xu et al., 2015). In terms of the global warming potential (CO_2-eq emission), the cumulative N_2O emission was lower than that of CH_4 emission from rice soil (Kurosawa et al., 2007). Previous studies also reported that N_2O emissions contribute much less to the global warming potential than CH_4 (Yan et al., 2005; Itoh et al., 2011; Pittelkow et al., 2013; Sander et al., 2015; Tarlera et al., 2016). Therefore, decreasing mainly the CH_4 emissions from rice soil is the most effective way to mitigate total greenhouse gas emission from rice production. However, the effect of AWD management under modified planting techniques on CH_4 emission, and its potential trade-off with increased N_2O emission from rice paddy, has not yet been investigated in South India, where 28% of Indian rice is grown.

Although there are many advantages of using the AWD irrigation practice, it is not easy for practical use by farmers; unless simple irrigation indices are developed, it is difficult for them to decide the best time for irrigating their crop. The International Rice Research Institute (IRRI) and Institute for Agro-Environmental Science (NIAES) developed a set of simplified guidelines for AWD irrigation system, using a field water tube as a tool to monitor the water level below the soil surface (Minamikawa et al., 2015). They used a perforated field water tube so that the water table is easily visible. Irrigation is applied when the perched water table falls to 15 cm below the soil surface. The threshold of 15 cm is called "safe AWD" as this does not cause any decline in the yield. However, the performance of safe AWD technology under modified planting method has not yet been evaluated in South India, where double cropping of paddy rice is practiced per year. In Tamil Nadu, the sixth largest rice-producing state in India, 89% of about 2 M ha paddy area is under irrigated conditions, of which, 54% of the paddy rice is irrigated by pumping of underground water; thus, AWD would allow farmers to control their irrigation during the two rice crop seasons in a year. There is a huge potential to reduce the irrigation water use and mitigate greenhouse gas emissions from paddy rice fields by practicing modified cultivation systems in Tamil Nadu, South India. Therefore, this experiment was conducted to (i) assess the effects of modified rice cultivation systems on water usage, crop yield, and methane and nitrous oxide emissions, (ii) compare rice varieties in terms of rice yield and GHG emissions, and (iii) evaluate global warming mitigation potential of modified cultivation systems for a sustainable rice production in both summer (dry) and monsoon (wet) seasons in Tamil Nadu, South India.

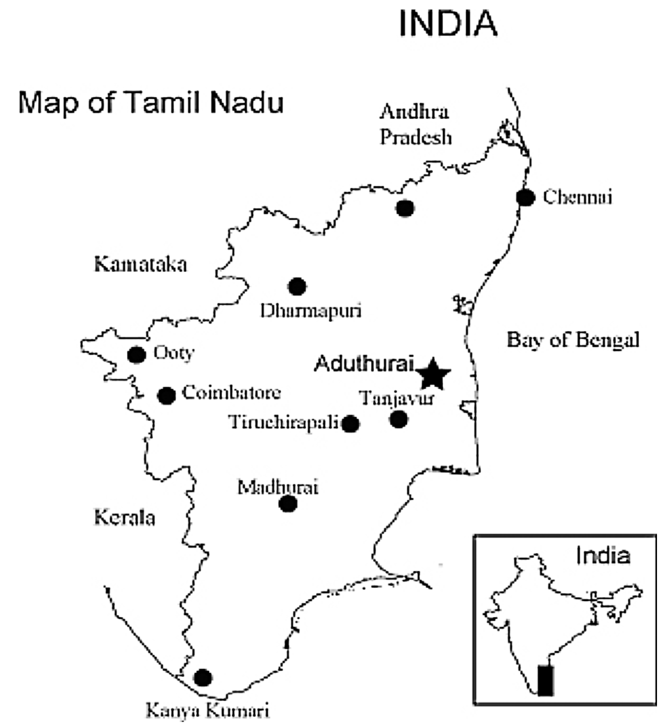

Fig. 1. Location of the experimental site in Aduthurai, Tamil Nadu, India. The site is characterized flat terrain in the Kaveri river system. ArcGIS 10.1, ESRI, Redland.CA. https://www.esrij.com/products/arcgis-for-desktop. GADM: Global Administrative Areas (2012). GADM database of Global Administrative Areas, version 2.0 [online] URL:gadm.org.

2. Materials and methods

2.1. Experimental site and design

The field experiments were carried out from May 2016 until January 2017, during two rice growing seasons, at the Tamil Nadu Rice Research Institute (TRRI), Aduthurai, Thanjavur District, Tamil Nadu (11°0′N, 79°30′E, 19.4 m MSL), South India (Fig. 1). The agro-ecological conditions in the area were: a tropical wet and dry/savanna climate with a pronounced dry season in the high-sun months, and no cold or wet seasons (monsoon season) in the low-sun months, with an annual precipitation of 1292 mm in 2015. The rainfall, and minimum and maximum temperatures during the experimental period, as recorded at the meteorological observatory of TRRI, are shown in Fig. 2. The soil was classified as Alluvial clay (United States Department of Agriculture, USDA classification). A rice–rice (*Oryza sativa* L. ssp. *indica*)-black gram (*Vigna mungo*) cropping rotation system is the typical practice in this area. The experimental soil was composed of: 1.1 g kg^{-1} total nitrogen (N), 19.6 g kg^{-1} total carbon (C), pH 7.5 (1:5H_2O) and EC 11.6 mS m^{-1}, 13.6% sand, 61.2% silt, and 25.3% clay (Inubushi et al., 2017).

There were two crop seasons, summer – hot and dry season (local name – Kuruvai season; from May to September) and monsoon – wet season (local name – Thaladi season; from September to January) in this experiment. The experiment was laid out in a split plot design with three replications. The two set of factors included in this experiment were as follows: three different planting methods, i.e., i) transplanting old seedlings with narrow spacing with continuous flooding (ON-CF), ii) transplanting young seedlings, wide spacing with alternate wetting and drying irrigation (YW-AWD), and iii) in-between conventional practice and YW-AWD (IB-AWD) as main plots, and two currently grown rice varieties, i.e., variety ADT 43 and CO 51 in summer season and variety ADT 46 and TKM 13 in monsoon season, as sub plots. Each experimental plot measured 7 m × 5 m. To prevent lateral seepage, we