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Mitigation of greenhouse gas emission from rice–wheat system of the Indo-Gangetic plains: Through tillage, irrigation and fertilizer management

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A B S T R A C T

Rice–wheat cropping systems (RWCS) of the Indo-Gangetic plains (IGP) of India are tillage, water and energy intensive and an important source of greenhouse gas (GHG) emission. Developing agronomic management in RWCS that lead to minimum adverse impact on soil, enhances water use efficiency, reduces GHG emission and are climate resilient is required. The aim of this study was to evaluate different combinations of GHG mitigation technologies for rice and wheat and to find suitable low carbon options for RWCS in the IGP. Seven management systems i.e. conventionally tilled wheat (CTW); zero tilled wheat (ZTW); transplanted puddled rice (TPR); dry direct seeded rice (DSR); intermittent wetting and drying (IWD); application of neem oil coated urea (NOCU); and surface application of rice residue (RR) were experimented in six combination of rotations [CTW-TPR, ZTW-TPR, ZTW-IWD, ZTW-DSR, ZTW + RR-DSR and (ZTW-TPR) + NOCU] for two consecutive years. Among these rotations, ZTW-DSR and ZTW + RR-DSR showed the lowest global warming potential (GWP) and GHG intensity in both the years. Adoption of these systems in the Indian-IGP can reduce GWP of the conventional RWCS (CTW-TPR) by 44–47% without any significant loss in the system yield. This was mainly due to significantly low CH_4 emission (82.3–87.2%) in DSR as compared to TPR due to prolonged aerobic condition under DSR. However, frequent wetting and drying in DSR led to higher denitrification emissions of N_2O (60–70%). Significantly higher emissions of N_2O were observed in ZTW treatments (8–11%). NOCU was found effective in reducing N_2O emission from ZTW (17.8–20.5%) leading to lower GWP as compared to CTW. Application of rice residue in ZTW treatment also reduced N_2O emission (11–12.8%). There was no significant effect of different treatments in rice on GHG emission from the succeeding wheat crop; however, ZTW and ZTW + RR were found to enhance CH_4 emission from the succeeding rice treatments.

1. Introduction

The yield of major staple food crops (wheat, maize, rice and soybean) in many regions of the world is being negatively affected by climate change (IPCC, 2014). On the other hand, agriculture is also one of the major causes for this change. Agriculture, forestry and other land use sectors contribute about a quarter (10–12 Gt CO_2 eq. yr^{-1}) of net anthropogenic greenhouse gases (GHG) emissions (IPCC, 2014). The intensively cultivated rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.) cropping system (RWCS) of the Indo-Gangetic plains (IGP) plays a major role in the food security of south Asia and is a potential source of GHG and vulnerable to climate change. The demand for these two cereals is expected to grow between 2% and 2.5% per annum until 2020, requiring continued efforts to increase productivity while ensuring sustainability (Gupta and Seth, 2007) and low GHG emission. This system has also started to show lower marginal returns, physical and chemical deterioration of the soil and decline in groundwater level in recen past (Chauhan et al., 2012).

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Rice–wheat system covers about 13.5 million hectares in the IGP with a marked concentration in the Indian IGP (10.5 million hectare). The Indian IGP occupying about 53% of total area under RWCS in India produces about 50% of the total food grains and feeds almost 40% of the of the country's population (Dhillon et al., 2010; Panigrahy et al., 2010). The conventional practice of rice and wheat cultivation in this region is tillage, water and energy intensive and a source of GHG emission (Gupta et al., 2015; Wassmann et al., 2004). Rice is mainly transplanted on puddled, water saturated anaerobic soil prepared by repeated wet tillage (puddling) and the field is submerged with water during the entire crop growth period while, wheat seed is sown on well aerated tilled soil (Gupta et al., 2015). Anaerobic rice fields are a major source of CH_4 while application of nitrogenous fertilizer leads to emission of N_2O from both the crops (Wassmann et al., 2004). The intensive tillage and frequent irrigation consume high amount of energy and is also a significant source of CO_2 (Gupta et al., 2015). Puddled rice in India contributes about 24% of the total agricultural CH_4 emission (3.37 Mt) while about 0.14 Mt N_2O is emitted due to application of nitrogenous fertilizer in rice, wheat and other crops (Bhatia et al., 2013a). To meet the future demand of food grains, increased application of fertilizer will be required leading to higher emissions of N_2O. Many studies indicate that climate change will result in increased N_2O emissions by affecting the N cycling rates as well as plant N demand by influencing the growth rates (Del Grosso and Parton, 2012; Xu-Ri et al., 2012).

Many approaches have been identified for mitigating GHG emission from RWCS. Adhya et al. (2000), Ahmad et al. (2009), Bhatia et al. (2010), Jain et al. (2014a), Liu et al. (2011), Ma et al. (2013), Majumdar et al. (2002), Pandey et al. (2012) and Pathak et al. (2012) have reported some technologies like direct seeded rice (DSR); intermittent wetting and drying (IWD) in transplanted puddled rice (TPR); mid-season drainage in TPR; zero tilled wheat (ZTW); use of nitrification and urease inhibitor; and application of crop residue in soil, for reducing GHG emission and enhancing water use efficiency. DSR does not require puddling, seeds are directly sown in tilled or no-tilled soil and have been reported to save water and labour as well as reduce CH_4 emission (Pathak et al., 2012). IWD of soil in rice not only saves irrigation water but also reduces emissions of CH_4 (Pathak et al., 2003). Sowing of wheat under zero tilled condition (ZTW) is another option which allows earlier planting of wheat, helps in the controlling of weed *Phalaris minor*, reducing production costs, saving water and fuel (Erenstein and Laxmi, 2008; Mileusnic et al., 2010). ZTW in the IGP of India has been reported to reduce carbon dioxide emissions, increase soil organic carbon and improve soil structure (Abdalla et al., 2013). Rochette et al. (2008) observed lower N_2O emissions under zero tilled soils as compared to conventionally tilled soils for semi-arid climates due to lower rates of nitrification. However, an increase in N_2O emission has also been reported in ZTW under semi-arid climatic conditions (Bhatia et al., 2010), and by Zhao et al. (2015) who carried out meta-analysis of 39 studies in no-till farming in China. The N_2O emission from soils will be governed by the moisture available for the processes of nitrification and denitrification (Zheng et al., 2000). Emission of N_2O can be reduced by efficient management of N (Bhatia et al., 2012) and by the use of nitrification inhibitors. Many synthetic nitrification inhibitors have been reported to be effective in the reduction of N_2O emission, however, their high cost do not make them a practical solution. Use of some natural inhibitors or slow release fertilizer like neem oil coated urea (NOCU) may be a cost effective as well as an environmentally friendly technology.

The management of rice residue is also a major problem in this zone. Due to its poor digestibility, low protein, high lignin and high silica contents, it is not suitable as cattle feed. Most of the farmers, therefore, burn rice residue on field to save time before sowing of the next crop i.e. wheat. This detrimental practice leads to nutrient loss, emission of GHG and air pollutants thereby posing threat to human health (Jain et al., 2014b). Retention of rice residue on soil surface of ZTW field may be a practical mitigation technology to reduce soil emissions, increase SOC and avoid residue burning.

These technologies have been evaluated for either rice or wheat and considerably less work has been carried out for the rice–wheat crop rotation as a whole (Bhatia et al., 2013b; Malla et al., 2005; Pathak et al., 2003). The adoption of various GHG mitigation technologies in a crop rotation might have a positive or negative impact on GHG emission and productivity of succeeding crop which needs to be evaluated. With this background, the objective of this study was to evaluate the emission of methane and nitrous oxide from technologies such as, DSR, IWD, ZTW, application of rice residue (RR) and nitrification inhibitor (NOCU) in wheat and rice and to identify low carbon emitting options for RWCS of the IGP in India.

2. Materials and methods

2.1. Characteristics of experimental site

A two year (2011–2012 to 2012–2013) field experiment growing wheat and rice in rotation was carried out at the experimental farm of Indian Agricultural Research Institute, New Delhi, located at 28°40′N and 77°12′E, at an altitude of 228 m above mean sea level in the trans Indo-Gangetic alluvial tract. The climate of the region is subtropical, semi-arid type with hot and dry summer and cold winter. The area receives an annual rainfall of 750 mm, about 80% of which occurs from June to September. The average temperature during wheat experimental season was about $18.5 \pm 5.9\,^{\circ}C$ and $18.3 \pm 5.8\,^{\circ}C$ respectively while during rice season it was $30.5 \pm 4.3\,^{\circ}C$ and $29.2 \pm 2.8\,^{\circ}C$ respectively in 2012 and 2013 (Fig. 1). The 2011–2012 was drier cropping season due to scarce rainfall while 2012–2013 was wet due to high and uniform rainfall (Fig. 1). The soil of the experimental site is Typic Ustochrept and loam (46% sand, 33% silt and 21% clay) in texture with bulk density of $1.38\,g\,cm^{-3}$, pH of 8.1, electrical conductivity of $0.48\,dS\,m^{-2}$, organic-C of 0.46%, total N (organic and inorganic) of $678\,kg\,ha^{-1}$, available P of $18.45\,kg\,ha^{-1}$ and available K of $284\,kg\,ha^{-1}$.

2.2. Treatments and cropping systems

A total of eight treatments, four in wheat and four in rice were studied in six combinations of wheat and rice rotation for two consecutive cycles (Table 1). The combinations of treatments in wheat followed by rice were convention tilled wheat-transplanted puddled rice (CTW-TPR), zero tilled wheat-transplanted puddled rice (ZTW-TPR), zero tilled wheat-intermittent wetting and drying in rice (ZTW-IWD), zero tilled wheat-direct seeded rice (ZTW-DSR), zero tilled wheat + rice residue-direct seeded rice (ZTW + RR-DSR) and zero tilled wheat + neem oil coated urea-transplanted rice + neem oil coated urea (ZTW-TPR)NOCU. The experiment was carried out in randomized block design (RBD) on the plot of 6×8 m dimension with three replications. During second year of the experiment, each treatment of wheat and rice were grown on the same block as the previous year to examine the impact of treatments on continuous wheat–rice rotation.

2.3. Crop management

The experiment was started in winter season with sowing of wheat (HD-2894) on 15 November, 2011 at the rate of 100 kg seed ha^{-1} followed by rice (PRH-10) on 26 June 2012 at the rate of 20 kg seed ha^{-1} for TPR and 30 kg seed ha^{-1} for DSR. In the next cropping season, same package and practices were adopted while sowing of