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Evaluation of fertilizer and water management effect on rice performance and greenhouse gas intensity in different seasonal weather of tropical climate

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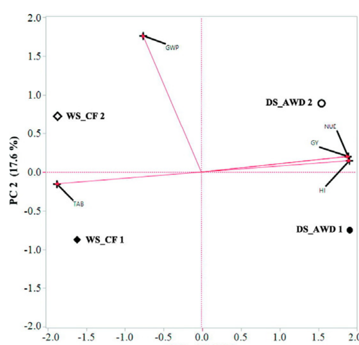
HIGHLIGHTS

- Cattle manure combined with urea fertilizer enhanced global warming potential under continuous flooding;
- $CaSiO_3$ application increased global warming potential despite reduction in N_2O emission under alternate wetting and drying;
- Utilizing urea was an optimal N to sustain rice production and minimize global warming potential in tropical climate;
- Alternate wetting and drying was effective in reducing global warming potential in double cropping rice system.

GRAPHICAL ABSTRACT



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ABSTRACT

Intensively double cropping rice increases greenhouse gas (GHG) emission in tropical countries, and hence, finding better management practices is imperative for reducing global warming potential (GWP), while sustaining rice yield. This study demonstrated an efficient fertilizer and water management practice targeting seasonal weather conditions effects on rice productivity, nitrogen use efficiency (NUE), GWP, and GHG intensity (GHGI). Two-season experiments were conducted with two pot-scale experiments using urea and urea + cattle manure (CM) under continuous flooding (CF) during the wet season (2013WS), and urea with/without $CaSiO_3$ application under alternate wetting and drying (AWD) during the dry season (2014DS). In 2013WS, 120 kg N ha^{-1} of urea fertilizer resulted in lower CH_4 emission and similar rice production compared to urea + CM. In 2014DS, $CaSiO_3$ application showed no difference in yields and led to significant reduction of N_2O emission, but increased CH_4 emission and GWP. Due to significant increases in GHG emissions in urea + CM and $CaSiO_3$ application, we compared a seasonal difference in a local rice cultivation to test two water management practices. CF was adopted during 2013WS while AWD was adopted during 2014DS. Greater grain yields and yield components and NUE were obtained in 2014DS than in 2013WS. Furthermore, higher grain yields contributed to similar values of GHGI although GWP of cumulative GHG emissions was increased in 2014DS. Thus, utilizing urea only application under AWD is a preferred practice to minimize GWP without yield decline for double cropping rice in tropical countries.

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1. Introduction

Increased greenhouse gas (GHG) emissions have increased the global warming potential (GWP) in all regions of the world, resulting in elevated global average temperature near the surface of the Earth. Methane (CH_4) and nitrous oxide (N_2O) are two important greenhouse gases in agricultural soils that cause chemical changes in the atmosphere. Irrigated rice fields have the potential to emit both CH_4 and N_2O simultaneously, but the magnitude of these emissions depends on agricultural management systems (Linquist et al., 2012). Paddy field and irrigated lowland rice cultivation systems significantly affect the emissions of CH_4 and N_2O (Cai et al., 1997; Yao et al., 2012). Linquist et al. (2012) estimated that the aggregate emission of CH_4 and N_2O in rice production systems was approximately four times higher than that of either upland wheat or maize systems.

Agricultural practices have the potential to mitigate GHG emissions. The most effective management practices to mitigate GHG emission for irrigated rice paddies, particularly to reduce CH_4 emissions, are water management practices during the rice-growing season (Trost et al., 2013; Yan et al., 2005). Appropriate water management strategies can substantially decrease GHG emissions (Feng et al., 2013). The most effective practices include midseason drainage and intermittent irrigation, which aims to improve rice growth by controlling surplus tillering and supplying rice roots with molecular oxygen (O_2) to prevent sulfide toxicity (Kanno et al., 1997). Another practice is alternate wetting and drying (AWD), which conserves water and reduces GHG emissions in rice cultivation while maintaining yields; AWD was developed by the International Rice Research Institute (IRRI) (Bouman et al., 2007). The AWD practice in Southeast Asia was adopted in rice cultivation during the dry season (DS) instead of the wet season (WS) because of water shortage in a rice–rice double cropping system. WS rainfall is typically sufficient to sustain rice crops, whereas additional irrigation is required for viable rice crops in the DS. The DS generally produces higher emissions than the WS due to high plant biomass (Sass et al., 1990; Ziska et al., 1998). However, lower emissions during the DS were also reported (Corton et al., 2000). Both rice-growing seasons can be significant sources of CH_4 and N_2O depending on fertilizer and water management practices. Significant CH_4 emissions may occur under continuously flooded soils, whereas N_2O emissions result if soils are alternately wet and dry (Bronson et al., 1997). Thus, the estimated GHG budget exhibited large spatio–temporal variations (Chakraborty et al., 2006).

Many studies have reported the effect of N fertilization on rice production and its relation to GHG emissions (Cai et al., 2007; Ku et al., 2016). In general, N fertilization can increase whole rice biomass productivity while resulting in vigorous growth in arenchyma, tiller number, and root biomass as well as releasing increased amount of labile carbon and CO_2 during the productive stages (Wassmann et al., 2000a). Under submerged paddy soils, CH_4 is produced from the soil due to the anaerobic condition of the soil. In theory, CH_4 has three different emission pathways to the atmosphere: diffusion through the water layer, ebullition (i.e. bubbling), and transport through the arenchyma of rice plants. Nitrous oxide is produced by ammonia-oxidizing bacteria and archaea via nitrification and denitrification processes in the soil (Santoro et al., 2011). The emissions of N_2O depend on the presence of water logging, soil Eh, and the amount and timing of the application of N sources (Cai et al., 1997; Zou et al., 2005). Under submerged paddy soils, N_2O emissions are normally inhibited due to an anaerobic condition by low soil Eh and most N gas is released as N_2 (Hou et al., 2000; Mosier et al., 1990). Under AWD, the soil microbial processes of nitrification and denitrification enhance N_2O emissions (Khalil et al., 2004; Wang et al., 2011). Nitrous oxide has higher global warming potential than CH_4, thus its emission from paddy soils should be controlled. Improving the efficiency and effectiveness of crop N use can potentially reduce N_2O emission by reducing the potential for elevated residual NO_3-N in the soil profile (Dobermann, 2007; Snyder and Bruulsema, 2007).

A silicate fertilizer such as $CaSiO_3$ was shown to be one of the promising strategies to mitigate GHG emission from rice cultivation (Ali et al., 2008). It is a byproduct of the steel industry and contains high amounts of active iron and free iron oxides, acting as an oxidizing agent that controls CH_4 emissions in submerged paddy soils. Slag-type silicate fertilizer used as soil amendment, along with nitrogenous fertilizer in rice cultivation, significantly decreased seasonal CH_4 flux by 16–20% and increased rice productivity by 13–18% in Korean wetland paddy soils (Ali et al., 2008). In the upland rice paddy soils of Bangladesh, the same type of silica fertilizer with urea application decreased total seasonal CH_4 flux by 12–21% and increased rice grain yield by 5–18% (Ali et al., 2012). However, information on the effect of a silicate fertilizer on N_2O emissions is limited, and further study is needed to evaluate the effect of this fertilizer through evaluating N use efficiency.

In tropical countries, most farmers have applied animal manure or the combination of manure and synthetic N fertilizer as sources of N to produce rice yield. However, animal manure application may cause significant CH_4 emissions, especially under continuous flooding in the WS. Although AWD irrigation in the DS due to water scarcity has been recommended to suppress CH_4 emission, it has the risk of increasing N_2O emission mainly due to the use of synthetic N fertilizer. Current fertilizer and water management practices are focused on sustaining rice production while reducing GHG emissions. However, seasonal weather differences between the WS and DS are not taken into account and few studies have examined the effect of these seasonal differences. Our research examined fertilizer and water management effects on rice production, nitrogen use efficiency, and GHG emissions in a wet and dry season. A conceptual framework is provided (Fig. 1). The specific objectives of this study were to 1) determine an optimal N application based on rice production and GHG emissions, 2) elucidate the role of silicate in rice production and GWP of CH_4 and N_2O emissions under AWD irrigation, and 3) propose an efficient fertilizer and water management practice that takes in account seasonal weather effects on reducing GWP without reducing yield in a double cropping rice system.

2. Materials and methods

2.1. Experimental design

Two-season pot-scale experiments were consecutively conducted in a screen house at the IRRI during the wet season (WS), from May 29 to October 3, 2013 for experiment 1 (2013WS) and during the dry season (DS), December 20, 2013 to April 22, 2014 for experiment 2 (2014DS). Based on local field and climate conditions in Philippines, 2013WS was conducted with continuous flooding (CF) water management method during the WS since rainfall was sufficient to supply water for rice production. However, alternate wetting and drying (AWD) water management was applied for 2014DS because of water scarcity during the DS (Fig. 2a and b).

A polyethylene pail with a height of 700 mm, inner diameter of 530 mm, and capacity volume of 138 L was used as a pot and chamber. This experimental setup was adopted from the design of Furukawa et al. (2007) but modified to meet the requirements of the current experiment. The modified pot consists of a water-filled channel fitted at the top of the pot circumference to prevent the diffusion of gas after the chamber is closed. The chamber includes an ordinary thermometer and a vented silicon tube, which was fitted permanently at a quarter position in the head space and sealed with silicon septum for gas sampling. From the tillering stage of rice plants, a chamber extension made of opaque polyvinyl chloride (PVC) with a height of 200 mm and inner radius of 530 mm was prepared to accommodate rice growth during gas sampling. The outer surfaces of the pots and the gas-collection chambers were covered with aluminum foil to prevent an increase in temperature from sunlight.

Paddy soil, classified as *Andaqueptic Haplaquoll* (Raymundo et al., 1989), was collected from a plow layer in an IRRI experimental field