Geoderma 315 (2018) 1–10

Contents lists available at ScienceDirect

Geoderma

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

Combination of modified nitrogen fertilizers and water saving irrigation can reduce greenhouse gas emissions and increase rice yield

Jianling Li[a], Yu'e Li[a,*], Yunfan Wan[a], Bin Wang[a], Muhammad Ahmed Waqas[a], Weiwei Cai[b], Chen Guo[c], Shouhua Zhou[d], Rongsui Su[d], Xiaobo Qin[a], Qingzhu Gao[a], Andreas Wilkes[a]

[a] *Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences/Key Laboratory for Agro-Environment, Ministry of Agriculture, Beijing 100081, China*
[b] *College of Agriculture, Yangtze University, Jingzhou, Hubei Province 434025, China*
[c] *College of Resources and Environment, Huazhong Agricultural University, Wuhan, Hubei Province 430070, China*
[d] *Jingzhou Agro-meteorological Experimental Station, Jingzhou, Hubei Province 434025, China*

ARTICLE INFO

Handling Editor: Jan Willem Van Groenigen

Keywords:
Greenhouse gas emissions
Controlled release urea
Urease inhibitor
Nitrification inhibitor
Water saving irrigation

ABSTRACT

The combined impacts of modified nitrogen (N) fertilizers and water saving irrigation (WSI) on greenhouse gas (GHG) emissions and grain yield of rice paddies have not previously been documented. GHG emissions from rice paddies under modified N fertilizers and WSI deserve attention because water and N are being used extensively to attain higher grain yield. A field experiment was conducted to evaluate the influence of modified N fertilizers and WSI on methane (CH_4) and nitrous oxide (N_2O) emissions and grain yield in rice paddies. Four treatments were applied: urea with conventional irrigation (U + CI), urea with shallow water depth with alternate wetting-drying water saving irrigation (U + SWD), polymer-coated controlled release urea with SWD (CRU + SWD), and nitrapyrin-urea composition plus hydroquinone with SWD (NU + HQ + SWD). Compared to U + CI, CH_4 emissions significantly decreased by 26% and 31%, and N_2O emissions increased by 52% and 42% under U + SWD in the early and late rice growing seasons respectively ($p < 0.05$). Although SWD increased N_2O emissions, total GHG emissions (T_{GHG}) reduced by 20% and 25% in the two rice seasons under U + SWD, and GHG emission intensity (GHGI) decreased by 24% on average. Modified N fertilizer applications also affected grain yield and GHG emissions under SWD. Compared with U + SWD, CRU + SWD and NU + HQ + SWD reduced CH_4, N_2O emissions and T_{GHG} by 28–49%, 12–44% and 26–45%, respectively, while grain yield increased by 6–35%. Reduction in CH_4 emissions occurred because, compared to urea, CRU and NU + HQ can inhibit CH_4 production and transport by controlling development of invalid tillers, while their nitrogen release patterns were more favorable for CH_4 consumption. In summary, modified N fertilizers in combination with SWD are a win-win strategy to improve grain production while reducing GHG emissions in the rice cropping system.

1. Introduction

Greenhouse gas (GHG) emissions from rice-based production systems are higher than from other cereal cropping systems (Carlson et al., 2017). The double rice production system in South China uses continuous submergence conditions for about six months, which creates an anaerobic environment supportive of methane (CH_4) production. At the global scale, CH_4 emissions from rice paddies are estimated to be 20–40 Tg yr^{-1}, accounting for a significant share (10–20%) of annual anthropogenic CH_4 emissions to the atmosphere (Smith et al., 2007). Rice cultivation also emits nitrous oxide (N_2O), and emissions are largely controlled by water and N management. Although estimated N_2O emissions are much lower (32 Gg N_2O-N yr^{-1}) than CH_4 emissions from rice cultivation in China, N_2O emissions are likely to increase with an increasing N application rate (Xia et al., 2016). Irrigation and N fertilizer are key inputs for optimizing grain yield. Therefore, modifications in current water and N management practices are needed to improve the grain yield while limiting the environmental impacts of rice cropping systems.

China is a major global rice producer, accounting for 18.8% of harvested area and 28.1% of global rice production (FAO, 2014). Traditional irrigation practices in rice paddies consume a large amount of water. The annual irrigation volume used for rice production accounted > 60% of total water use in China (Jiang et al., 2017). Rice production is threatened by regional and seasonal water shortages caused by drought (Schewe et al., 2014). Increasing water consumption

---

[*] Corresponding author.
E-mail address: liyue@caas.cn (Y. Li).

https://doi.org/10.1016/j.geoderma.2017.11.033
Received 8 April 2017; Received in revised form 5 August 2017; Accepted 21 November 2017

by industry and urban areas further exacerbates agricultural water scarcity (Xiong et al., 2010). Thus, water saving irrigation (WSI) technology is essential to minimize water use in rice production systems.

Several WSI technologies have been developed and popularized in China, such as alternate wetting and drying, soil saturated cultivation, bed-furrow base irrigation and non-flooded mulching cultivation (L. Liu et al., 2013; Xu et al., 2015). In most cases, compared to continuous flooding, WSI maintains or increases rice yield (L. Liu et al., 2013), although some studies have reported contrary findings (Linquist et al., 2015; Xu et al., 2015), because the impact of WSI depends on rice varieties, climatic factors, soil retention capacities, irrigation volumes, and irrigation scheduling (Linquist et al., 2015; Xu et al., 2015).

Soil water status is responsible for CH_4 formation and emission. Compared with continuous flooding, WSI shows a significant potential to mitigate CH_4 emissions (Xu et al., 2015). Most WSI practices involved one or more drainage events to suppress CH_4 production. However, substantial N_2O emissions may be triggered by wet-dry cycles (Wang et al., 2011). Shallow water depth with alternate wetting-drying (SWD) is a compound irrigation technology involving shallow water irrigation, mid-season drainage, and control irrigation practices. So far, few studies have reported the impacts of SWD on GHG emissions from paddy fields.

Increases in rice grain yields have mostly been attributed to improvements in N fertilizer application (Chen et al., 2014). But excessive use of N has led to decreasing N use efficiency and generating a cascade of environmental issues, such as water pollution (Zhang et al., 2011), soil acidification (Chen et al., 2014), ammonia volatilization, and GHG emissions (X.J. Liu et al., 2013). Recently, the application of modified N fertilizers, such as controlled release urea (CRU), urease inhibitor (UI) and nitrification inhibitor (NI) in rice paddies have shown the potential to achieve high grain production while reducing N_2O emissions (Qiao et al., 2015). However, the impact of modified N fertilizer application on CH_4 emissions remains unknown.

Past studies have investigated either the effects of modified N fertilizers (Qiao et al., 2015; Wang et al., 2016) or WSI practices (Tyagi et al., 2010; Xu et al., 2015) on GHG emissions and rice yield. Therefore, it is timely to investigate whether the potential for decreases in grain yield and increases in N_2O emissions under WSI adoption can be offset by the application of modified N fertilizers. This study aimed to evaluate the combined impacts of WSI and modified N fertilizers on GHG emissions and rice yield, and to investigate the underlying mechanisms on controlling GHG emissions from rice production systems when modified N fertilizers are applied.

2. Materials and methods

2.1. Experimental site

The study was conducted at the Agro-meteorological Experimental Station, Jingzhou, Hubei Province, China (30°21′ N; 112°09′ W) in 2015. The station is located in a humid monsoon climate zone. Meteorological data during the experimental period were recorded by Jingzhou Agro-meteorological Experimental Station. Daily average air temperature and seasonal total precipitation were 24.5 °C and 431 mm for the early rice season, and 24.3 °C and 297 mm for the late rice season, respectively (Fig. 1). The soil at the experimental site is classified as a hydragric paddy soil with a medium loam texture. Soil physicochemical properties (0–20 cm depth) were: pH, 7.7; organic carbon 13.58 g kg^{-1}; total N 1.45 g kg^{-1}; available phosphorus 13.5 mg kg^{-1}; available potassium 69.0 mg kg^{-1}; and clay, silt and sand content of 28.3%, 42.2% and 29.5%, respectively.

2.2. Experimental design and agronomic practices

Three types of N fertilizers were adopted in the experiment: (1) urea (N ≥ 46%) (U); (2) polymer-coated controlled release urea (N ≥ 42%) (CRU), with an N release time exceeding 90 d; (3) nitrapyrin-urea composition (N ≥ 46%) with hydroquinone (NU + HQ). Nitrapyrin-urea composition included 0.5% nitrapyrin, and hydroquinone (a urease inhibitor) was applied at 1% of the N fertilizer rate.

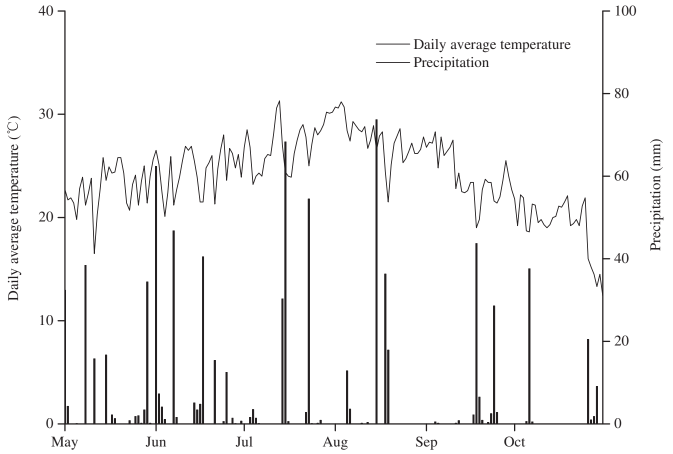

Fig. 1. Daily average temperature and precipitation during the early and late rice growing seasons in 2015.

Two water regimes were applied during the rice growing seasons: (1) conventional irrigation (CI), characterized by maintaining paddies continuously flooded after transplanting, and draining at late tillering and maturity stages; and (2) SWD. SWD is a novel WSI technology. Under SWD, the water layer in the paddy field is maintained at 20–30 mm at the re-greening stage. At booting and heading stages, a 5–20 mm shallow water layer is maintained to avoid yield loss. During the tillering and milk maturity stages, fields are irrigated to a water depth of 10 mm, and the water is allowed to deplete through percolation and evapotranspiration until soil moisture reaches critical values (i.e. 75% and 70% saturated soil moisture content at tillering and milk maturity stages, respectively). Plots were drained at the end of the tillering stage and re-flooded when soil moisture equaled to 60% saturated soil moisture content. Plots were drained again from the yellow maturity stage to harvest. Details of water management practices at different stages are given in Table 1.

A single factor randomized complete block design was employed with four treatments and three replicates. The treatments were: (1) urea with conventional irrigation (U + CI), which was taken as the control treatment; (2) urea with SWD (U + SWD); (3) polymer-coated controlled release urea with SWD (CRU + SWD); and (4) nitrapyrin-urea composition plus hydroquinone with SWD (NU + HQ + SWD).

N fertilizers were applied in three splits (basal fertilizer before rice transplanting, top dressing at the early tillering stage and at panicle initiation) at a rate of 165 and 180 kg N ha^{-1} in the early and late rice seasons, respectively (Table 2). CRU was applied only as a basal dose and at the tillering stage because the release period was over 90d. Potassium fertilizer was applied at 90 kg K_2O ha^{-1} (30% as basal fertilizer, 25% as tillering fertilizer, and 45% as panicle fertilizer). Phosphate fertilizer was applied at 60 kg P_2O_5 ha^{-1} as basal fertilizer.

Each plot area was 27 m^2 (4.5 m × 6 m) and separated by ridges (0.2 m high × 0.3 m wide). In order to prevent water movement between adjacent plots, ridges were covered with plastic sheet inserted into the soil at a depth of 0.5 m. Pipes and water flow meters were installed for irrigation control. An individual drainage outlet was set up for each plot. Except for water and N fertilizer management, other field operations were consistent with local farming practices.

Liangyou 287 and Xiangfengyou 9, which are the major rice varieties in the study region, were planted in the early and late rice seasons, respectively. The 3-week-old seedlings were transplanted to paddy fields at a density of 20 cm × 25 cm, with 2 seedlings per hill. Further field management details are given in Table 3.