Agricultural Water Management 177 (2016) 241–247

Contents lists available at ScienceDirect

Agricultural Water Management

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

# Response of first flood irrigation timing after rice dry-direct-seeding: Productivity and greenhouse gas emissions in Central China

Qingwei Jiang[a], Weiqin Wang[a], Qian Chen[a], Shaobing Peng[a], Jianliang Huang[a], Kehui Cui[a], Lixiao Nie[a,b,*]

[a] National Key Laboratory of Crop Genetic Improvement, MOA Key Laboratory of Crop Ecophysiology and Farming System in the Middle Reaches of the Yangtze River, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei 430070, China
[b] Hubei Collaborative Innovation Center for Grain Industry, Yangtze University, Jingzhou, Hubei 434023, China

ARTICLE INFO

*Article history:*
Received 18 January 2016
Received in revised form 3 August 2016
Accepted 4 August 2016

*Keywords:*
Dry direct-seeded rice
First flood irrigation time
Yield
Water productivity
Greenhouse gas emission

ABSTRACT

A major challenge in rice (*Oryza sativa* L.) production is to simultaneously achieve the goals of reducing water consumption, labor requirements and greenhouse gas (GHG) emissions while maintaining a sustainable grain yield. Dry direct-seeded rice (DDSR) has been proposed as an alternative rice production strategy because it reduces water consumption and labor requirements and increases system productivity. To evaluate the responses of grain yield, yield components, water productivity and GHG emissions to different first flood irrigation times under DDSR, field experiments were conducted under three different first-irrigation times: 15, 30 or 45 days after sowing (DAS) in 2014 and 15, 35 or 55 DAS in 2015. The precipitation in the 45 DAS was 291 mm in 2014 and 160 mm in 2015. The results indicated that the grain yields under DDSR were not affected by the different flooding times in 2014 but were significantly reduced when the first flood irrigation time was prolonged to 55 DAS in 2015. Delaying the first flood irrigation time after sowing conserved water and significantly increased water productivity (WP) under DDSR. Prolonging the first flood irrigation time after sowing markedly decreased the $CH_4$ gas emission, although delaying the first flood irrigation time increased the $N_2O$ gas emission, the global warming potential was significantly reduced. Based on these findings, we put forward the recommendation that the timing of first flood irrigation can be postponed to 45 DAS with precipitation levels higher than 160 mm under DDSR in central China. However, long-term studies across different environments are inevitable to get definite conclusions.



## 1. Introduction

Rice is the staple food for more than half of the world's population and is grown in more than 95 countries across the globe (Coats, 2003; Maclean et al., 2002), and the worldwide demand for rice is predicted to increase by approximately 24% over the next 20 years (Van Nguyen and Ferrero, 2006). However, because of scarce resources and fragile environments, rice cultivation must be achieved while using less resources and producing lower GHG emissions. Thus, more effective cultivation management should be adopted for rice production. Dry direct-seeded rice (DDSR) is the process of establishing rice crop from seeds sown in non-puddled and unsaturated soil (Liu et al., 2014, 2015). Compared with transplanted rice (TR), DDSR conserves a greater amount of water and is less labor intensive during the rice seedling nursery and transplantation phases (Kumar and Ladha, 2011) and produces less GHG emissions throughout all growth stages (Hussain et al., 2015; Tao et al., 2016).

In China, agricultural water use accounts for 65% of the total consumption of fresh water, and rice cultivation accounts for 50% of the agricultural water usage (Peng et al., 2009). The irrigation efficiency in China has been reported as only 0.5, a rate that represents half the irrigation efficiency in many advanced countries (Bouman, 2009). A shortage of water resources and low water productivity threaten the sustainable development of rice production in China. Therefore, effective measures should be implemented to

* Corresponding author at: National Key Laboratory of Crop Genetic Improvement, MOA Key Laboratory of Crop Ecophysiology and Farming System in the Middle Reaches of the Yangtze River, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, Hubei 430070, China.
*E-mail address:* nielixiao@mail.hzau.edu.cn (L. Nie).

http://dx.doi.org/10.1016/j.agwat.2016.08.006
0378-3774/

improve the WP of rice cultivation, especially in China (Wang et al., 2014).

Parry et al. (2007) reported that rice cultivation is the most significant cause of agricultural GHG emissions and a contributory factor to global warming. The increasing demand for rice has resulted in more GHG emission and consequently, more negative environmental impacts of rice cultivation (Van Beek et al., 2010; Zhang et al., 2011), and similar results have been reported in a number of studies (Matson et al., 1997; Tilman, 1999; Vitousek et al., 2008). Rice is usually grown under anaerobic conditions, and the increased production of active methanogens generates a greater amount of GHG emissions (primarily $CH_4$) compared with that of upland crops (Linquist et al., 2012). Thus, to reduce GHG emissions, DDSR has been considered the best option for rice production (Hussain et al., 2015).

A number of researchers have asserted that DDSR can conserve water and reduce labor; however, the grain yield under DDSR is relatively lower than that under TR (Miyagawa et al., 1998; Tomita et al., 2003; Zheng et al., 2016). In the past, DDSR studies have primarily focused on the variable yield response according to the locations and cultivars, and previous studies have indicated that the yield under DDSR is 20% lower than the yield under TR (Johnson et al., 2003). However, some other studies have reported comparable or an even higher yield of DDSR compared with TR (Kato et al., 2009; Katsura and Nakaide, 2011; Matsunami et al., 2009; Totin et al., 2013). Zhao et al. (2007) reported that DDSR conserved 25–50% water while producing a yield comparable to TR. Similarly, Zhu (2008) documented that DDSR increased grain yields by 22% and reduced water inputs by 6000 $m^3$ $ha^{-1}$ compared with TR. Previous studies have indicated that yield reductions caused by water stress are dependent on variations in plant sensitivity to water stress at different rice growth stages (Zhang et al., 2005). Rice sensitivities to water stress follow the order panicle initiation (PI) stage > heading (HD) stage >mid-tillering (MT) stage (Zhang et al., 2005). According to these conclusions, we assume that the reduced water input during the early vegetative stage may have less of an effect on the grain yield under DDSR. Moreover, DDSR can reduce global warming potential (GWP) because crops are grown under aerobic conditions for a relatively longer period of time (Maraseni and Cockfield, 2012). To ensure food security and reduce GHG emissions, an optimum first irrigation time after dry direct seeding under DDSR must be identified. To evaluate the responses of grain yield, yield components, water productivity and GHG emissions to different first flood irrigation times under DDSR, field experiments were conducted using three different first flood irrigation times. The objectives of the study were to determine the optimal time to start flood irrigation for achieving maximum economic, environmental and social benefits under DDSR in central China.

## 2. Materials and methods

### *2.1. Site description*

The field experiments were conducted at the Zhougan Village (29°51′N, 115°33′E), Dajin Town, Wuxue County, Hubei Province, China in 2014 and 2015. The soil samples were collected from the upper 20 cm of the surface. The pH, organic matter, total nitrogen (N), available phosphorus, and extractable potassium were 5.0, 20.43 g $kg^{-1}$, 0.15%, 31.51 mg $kg^{-1}$, and 132.2 mg $kg^{-1}$, respectively. The groundwater levels were recorded during the rice growth durations in 2014 and 2015. The average value of groundwater depth during the two years was 28 cm from sowing to first irrigation and 14 cm after irrigation till harvest. And the soil mass water contents were 30% at land preparation, 34% at sowing, and 40% at 5 days after sowing.

### *2.2. Experimental design*

Three different first flood irrigation times after sowing were randomly arranged using a split-plot design (6.5 m × 3.5 m), and each main plot was separated by bands with plastic film. The starting irrigation times were assigned to the main plots, and the cultivars were assigned to the sub-plots with four replicates. Two indica rice cultivars were used: Huanghuazhan (HHZ, inbred) and Yliangyou1 (YLY1, hybrid). These two cultivars were mega varieties in the experimental site, which were widely planted as transplanted rice under lowland conditions. The expected yields under lowland conditions are 8.0-9.0 t $ha^{-1}$ for HHZ and 9.5-10.5 t $ha^{-1}$ for YLY1 in the site. In 2014, the different first flood irrigation times were 15, 30 and 45 DAS. Because the plant growth and grain yield of DDSR were not markedly affected by different first flood irrigation times in 2014, the first flood irrigation times were adjusted to 15, 35, and 55 DAS in 2015. The sowing dates were May 3rd in 2014 and April 28th in 2015. The harvest dates were 3rd September (HHZ) and 20th September (YLY1) in 2014, while 27th August (HHZ) and 7th September (YLY1) in 2015.

In both years, the soil was dry ploughed and harrowed without puddling. The dry rice seeds were sown in 25 cm wide rows at a sowing rate of 60 kg $ha^{-1}$ using hand drill. A fertilizer dose of 180:40:100 kg $ha^{-1}$ of N:P:K was applied in the form of urea, calcium superphosphate, and potassium chloride, respectively. N was applied at soil preparation, MT, PI and booting (BT) stages in the proportion of 5:5:5:3. All of the P and half of the K were applied during soil preparation as the basal starter dose, and the other half of the K was applied at the panicle initiation stage. Weeds, insects and diseases were intensively controlled throughout the growing season to avoid yield losses in both years.

### *2.3. Water input measurements*

Before the first flood irrigation, the plots were maintained under rainfed conditions, whereas after the first flood irrigation, the plots were maintained with a 5–10 cm water layer up to one week before harvest. The daily precipitation during the crop growth period was recorded by a rain gauge located in the center of the experimental field. A flow meter was installed in the irrigation pipelines to monitor the amount of irrigation water. Water productivity (WP, kg grain $m^{-3}$ water) was expressed as the ratio of grain yield to amount of irrigation water applied plus rainfall.

### *2.4. Greenhouse gas flux measurements*

In 2015, the$CH_4$ and $N_2O$ fluxes were determined using the closed-chamber technique (Pathak et al., 2002) using two chambers with different sizes (0.5-m length × 0.3-m width × 0.65-m height and 0.5-m length × 0.3-m width × 1.3-m height). The chamber consisted of acrylics and six flux collars. All of the chambers were composed of the same materials with the same lengths and widths. The base of each chamber was permanently installed in the fields during the rice growing season. The top edge of the collar base has a groove (5 cm in depth) that can be filled with water to seal the rim of the chamber during gas sampling. An electric fan was operated to ensure complete gas mixing, and the chambers were covered by sunshade cloth to minimize air temperature changes inside the chamber during the sampling period. Gas sampling was started at 30 DAS and performed in intervals of seven days. The gases were sampled from inside the chambers using 100-mL plastic syringes fitted with three-way stopcocks at 0, 10, and 20 min after chamber closure and then infused into an empty aluminum foil gas collecting bag. The sampling times were between 9:00 AM and 11:00 AM on each sampling day, and the gas samples were transported to the laboratory for analysis by gas chromatography (GC) within a few