



# Effect of water and rice straw management practices on yield and water productivity of irrigated lowland rice in the Central Plain of Thailand

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## ABSTRACT

Rice cultivation techniques with less irrigation water input are crucial for global food security in the context of changing climate scenarios. Alternate wetting and drying (AWD) is among such water-saving techniques, which could potentially reduce irrigation water input for rice cultivation through alteration of soil submergence period with period of soil non-submergence (unsaturated soil conditions) during the growing season. Rice straw is often scattered in the field after harvest or burned in intensive rice cultivation systems. Response of irrigated lowland rice with respect to grain yield and water use under different water and rice straw management practices largely remains unknown. Field experiments were conducted at the Ayutthaya Rice Research Center, Ayutthaya, Thailand, in two consecutive rice-growing seasons (wet and dry) of 2016–2017 to evaluate the growth, yield and water productivity of irrigated lowland rice under different water and rice straw management practices. The treatments included were two water (continuous flooding [CF] and AWD) and three rice straw management practices (rice straw incorporation [RS-I], rice straw burning [RS-B] and without rice straw incorporation and burning [WRS-I + B]). AWD increased grain yield by 15% in the wet season and by 7% in the dry season compared with CF. Other yield components such as panicle number m<sup>-2</sup>, spikelet number panicle<sup>-1</sup> and 1000-grain weight were also higher under AWD compared with CF depending on the growing season. AWD reduced total water input by 19% in the wet season and by 39% in the dry season resulting in an improvement in total water productivity by 46% in the wet season and by 77% in the dry season relative to CF. Rice straw application either as soil incorporation or open-field burning had no effect on grain yield, water-saving potential and water productivity of the tested variety regardless of the growing season. Although its positive role in supplying plant nutrients and maintaining soil fertility, rice straw incorporation in the field or burning should be discouraged due to negative environmental impacts. AWD (15 cm threshold water level below the soil surface for irrigation or with soil water potential of  $\geq -20$  kPa [AWD15]) is recommended for irrigated lowland rice cultivation from a point of view of reducing total water input without jeopardizing yield.

## 1. Introduction

Thailand is among the major producers of rice (*Oryza sativa* L.) on a global scale (Ullah et al., 2018a). The Central Plain with its almost 30% rice production contributes the largest share in the national production where rice is cultivated both in the rainy season (May–October) and to irrigated area in the dry season (November–April). The soils in the Central Plain are predominantly composed of clay with a high water holding capacity. Both traditional transplanting and direct seeding methods of rice establishment are commonly practiced in the Central

Plain of Thailand. The area under direct seeding or broadcasting method was 1.72 million hectares (mha) in 2016 and 1.62 mha in 2017, whereas the area under transplanting was 0.12 mha in 2016 and 0.06 mha in 2017 (Office of Agricultural Economics (OAE, 2018). Transplanting is increasingly being replaced by seeding of pre-germinated seed to wet soil in irrigated rice production system to reduce production costs. Like most of the rice-producing countries, farmers' in Thailand usually apply more water than required to suppress weed populations causing excessive seepage and percolation losses and a resultant reduction in water productivity (WP). The area under

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irrigation and its associated cost (energy/fuel consumption in pumping) has significantly increased in the country in the past several years. The sustainability of irrigated rice production system has also been challenged by water scarcity due to climate change, and rapid urbanization and industrialization are further depleting water reserves and limiting the availability of irrigation water (Bouman and Tuong, 2001; Yan et al., 2015). These necessitate the adoption of water-efficient techniques to reduce water use in agricultural sector, while maintaining or increasing yield to support a growing population (Carrijo et al., 2017; Rijsberman, 2006). Cultivation techniques with less water demand, higher yield, less greenhouse gas (GHG) emission and more WP are ideally needed for sustainable rice production systems to improve food security in many Asian countries.

The popular continuous flooding (CF) system provides a favorable water and nutrient supply as well as weed management under anaerobic conditions; however, rice cultivation under this traditional system demands higher water input than other cereal crops (Datta et al., 2017; Nguyen et al., 2009). Various water-efficient techniques have been developed for rice cultivation in the context of decreasing irrigation water availability (Liu et al., 2015; Nie et al., 2011). Alternate wetting and drying (AWD) is among the most widely promoted water-saving irrigation technique introduced by the International Rice Research Institute (IRRI) to cope with increasing threat of water scarcity in rice cultivation (Belder et al., 2004; Bouman and Tuong, 2001; Datta et al., 2017). Under this system, fields are subjected to intermittent flooding (alternate cycles of saturated and unsaturated conditions) where water of about 2–5 cm is applied at an interval of 2–7 days depending on the soil type and weather condition followed by disappearance of ponded water from the soil surface and appearance of visible sign of some fine cracks on the soil surface (Tuong and Bouman, 2003).

AWD irrigation is an efficient technique that helps maintain sustainable rice production by saving water and reducing methane emission rate into the atmosphere (Watanabe et al., 2013; Liang et al., 2016). A reduction of 23% in water input has been reported under AWD compared with continuously flooded rice systems (Bouman and Tuong, 2001). Belder et al. (2004) reported that AWD technique can save water and reduce water use by 15–20% without jeopardizing yield. Moreover, AWD irrigation can help reduce annual methane emission by 57–78% from rice fields (LaHue et al., 2016). AWD can significantly reduce total water input in Thailand (Ullah et al., 2018b), thereby reducing input costs and improving farmers' livelihoods. In Thailand, the cost of water input for rice production is about US\$ 142.3 ha<sup>-1</sup> crop<sup>-1</sup> and a slight reduction in irrigation water input could be financially remunerative for the farmers (Office of Agricultural Economics (OAE, 2018). Apart from reducing water input, while maintaining or increasing yields and methane emission, some other benefits associated with AWD include enhancement in nutrient uptake, better root growth, more grain filling rate, remobilization of carbon reserves from vegetative tissues to grains and reduction of energy/fuel consumption where irrigation is supplied by pumping (Chu et al., 2014; Liu et al., 2013; Nalley et al., 2015; Tuong et al., 2005; Ullah and Datta, 2018; Yao et al., 2012; Zhang et al., 2008, 2009, 2012). Poor management of rice straw in intensive rice cultivation systems is an environmental concern and its proper utilization could help achieve better yield.

In Thailand, a total of about 42 mt of rice straw is produced annually and out of which almost 10 mt is generated in the Central Plain (Office of Agricultural Economics (OAE, 2018). About 69% of rice straw produced in the country is burnt (open-field burning) due to limited time availability to prepare the field for the next crop and easiness in field maintenance. Rice straw is also left scattered in the field after harvest. Rice straw incorporation has positive relationship to soil fertility and ecological environment (Wang et al., 2015). The burning practice is less laborious than straw incorporation, but has environmental consequences in the form of air pollution and emission of GHG (Wang et al., 2015, 2016). The inefficient use of freshwater and rice straw is a major concern in rice production systems in Thailand. Grain

yield and water use of irrigated lowland rice under different water and rice straw management practices are not well documented. We hypothesized that rice straw incorporation along with AWD (15 cm threshold water level below the soil surface for irrigation, AWD15) would be a better approach for maintaining soil moisture status and supplying nutrients, thereby reducing water input and increasing yield. Pathumthani 1, released for lowland rice fields in the Central Plain, is a photoperiod-insensitive variety (Ullah et al., 2017; Ullah and Datta, 2018; Ullah et al., 2018b), and is commonly grown in the Central Plain of Thailand having a yield potential of 4.45 t ha<sup>-1</sup> (Office of Agricultural Economics (OAE, 2018). The objective of the present study was to evaluate the growth, yield and water productivity of irrigated lowland rice (Pathumthani 1) under different water and rice straw management practices.

## 2. Materials and methods

### 2.1. Experimental site

Two field experiments were conducted during the wet (July–October 2016) and dry (November 2016–February 2017) rice-growing seasons of 2016–2017 at the Ayutthaya Rice Research Center (14°21'54.79"N, 100°36'19.71"E, 2 m above mean sea level), Ayutthaya Province, Thailand. The study area has two distinct seasons (wet and dry) and belongs to the tropical savanna climatic zone characterized by warm temperature throughout the year. The area receives an annual rainfall of 1000–1400 mm (almost all in the wet season) and experiences mean annual temperature of around 27 °C. The dry season lasts from November–April and the wet season lasts from May–October. The soil of the experimental field is classified as Ayutthaya soil series originated from a marine sediment-mixed riverine alluvium having a ground water depth of > 2 m. The soil is poorly-drained clay at 0–15 cm depth with the main soil properties as follows: sand 14%, silt 22%, clay 64%, pH (1:1 soil-water) 6.0, organic matter 1.41%, total C (w/w) 0.95%, total N (w/w) 0.16%, available P 17 mg kg<sup>-1</sup>, available K 201 mg kg<sup>-1</sup>, available Ca 5129 mg kg<sup>-1</sup>, available Mg 953 mg kg<sup>-1</sup> and electrical conductivity 0.81 dS m<sup>-1</sup>. The mean monthly temperature and total rainfall during the experimental period in the wet and dry seasons were 28.6 °C and 577.7 mm, and 27.7 °C and 80.8 mm, respectively (Fig. 1).

### 2.2. Experimental design and agronomic management

The experiment was repeated over seasons using split-plot design with three replications. The main plot was two irrigation management: CF and AWD (under AWD irrigation, irrigation was applied to a depth of around 5 cm when field water level dropped to 15 cm (soil water potential at –10 to –15 kPa) below the soil surface [AWD15]), whereas the subplot was three rice straw management: rice straw incorporation (RS-I), rice straw burning (RS-B) and without rice straw incorporation and burning (WRS-I + B). The individual plot size was 5 m × 7 m and plots were separated by a 1 m wide alley. Bunds (dikes) of 30 cm height were constructed along each side of the plot to prevent lateral water movement and were covered with black plastic film inserted to a depth of 30 cm below the soil surface.

In the wet season, seeds of Pathumthani 1 rice variety were sown by pre-germinated broadcasting method (wet direct seeding) into the main field on 5 July and harvested on 18 October 2016. The field was left idle for a short fallow period (about two weeks) after rice harvest in the wet season, and the same field was used for rice cultivation in the dry season. In the dry season, seeds of the same variety were broadcasted on 31 October 2016 and crops were harvested on 26 February 2017. The seed rate was 125 kg ha<sup>-1</sup> in both seasons. Pathumthani 1 is a photoperiod-insensitive variety, and the maturity period ranges between 106 and 126 days.

In the wet season, the plot under the CF treatment was continuously

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