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Rice Cultivation to Cope with Drought Situation by Alternate Wet and Dry (AWD) Water Management System: Case Study of Ratchaburi Province, Thailand

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Alternate wet and dry (AWD) system is an interesting water management system that has been widely promoted to replace continuous flooding (CF) system as an effective water saving technique for rice cultivation. This study was conducted in wet season of 2015 and dry season of 2016 in Ratchaburi Province, Thailand, with a randomised block design to estimate and compare the water used in rice cultivation and grain yield between AWD and CF systems. Water level controlling in rice field of AWD was incomplete in wet season experiment due to rainfall interference, but it was complete in the dry season experiment. It was found (non-significantly) that AWD used less water in rice cultivation than CF. It reduced water use by average about 8.13 % for the stages of transplanting to harvesting and 7.51 % for the stage of land preparation to harvesting. Dry field allowing of AWD has positive effects to tiller, panicle numbers and productivity which it increased grain yield by 2.42 % as compared to CF. This increase of grain yield can only be found in complete AWD (AWD in dry season). AWD also found significantly increased water productivity in both wet and dry seasons as compared to CF. Our result suggested that in the case study at Ratchaburi, although less water used in complete AWD than in CF, it was still not significant to show the effective of water used in the incomplete AWD system. More investigation in water consumption with no rainwater interfering is recommended.

1. Introduction

Thailand is an agricultural country and rice farming has become the way of life of Thai people since past to present and result to almost Thai people that still being farmers and growing rice. Farmers normally cultivate rice at least two times a year. Thailand has faced the drought situations for a long time until two years ago the government sought cooperation from farmers to refrain from rice cultivation in second season or switch from rice to other crops that need less water (Wipatayotin, 2016). The drought has led to the decline of rice production and farmers' income (Polthanee et al., 2014) and may push grain prices to be higher than the previous year's level which is a disadvantage for the consumer (Thaiturapaisan, 2015).

One of the ways rice cultivation can cope with the drought or water scarcity is reduction of water use particularly irrigation water because rice does not need to be submerged in water all time to grow. The irrigation that was developed by the International Rice Research Institute (IRRI) and has been considerably interesting to replace continuous flooding (CF) is alternate wetting and drying (AWD) (Price et al., 2013). AWD is water management that allow rice field to dry naturally in several times (after transplanting to before pregnancy stage) through percolation, seepage, and evaporation to reduce water input into the field (Adhya et al., 2014). It can reduce irrigation water by 28.0 % to 41.9 % as compared to CF (Ye et al., 2013). Dried field of AWD also promotes increase of productivity through rice tiller and panicle increase (Rahman and Bulbul, 2014). It is interesting to study the water use and grain yield of rice cultivation under AWD water management and compare with CF to identify the effective practice that can reduce water used and maintain (or improve) grain yield. It will be a practice that can help farmers in the planning and preparation of water supply or storage to rice cultivation particularly in dry season.

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2. Materials and methods

2.1 Experiment site

The experiments were conducted in 2015 and 2016 at King Mongkut's University of Technology Thonburi (KMUTT), Ratchaburi Campus (13° 35' 10" N & 99° 30' 21" E, 118 m above sea level) which is located in Ratchaburi province of Thailand (western region).

2.2 Field experiment and crop cultivation management

The seedling of Pathumthani 1 rice cultivar was transplanted in a rice field (distance between hill is 25 cm) by initially about 4 tillers per hill. This study cultivated rice for 2 seasons, wet season (Aug. to Dec. 2015), and dry season (Feb. to Jun. 2016). Each season comprised of two water managements which are CF and AWD. The experiment was carried out in a randomised block design in which each plot size is about 5 m x 4 m. During rice production season, chemical fertiliser at a rate of 90 kg N ha^{-1} was applied about two times per season which were at 20 d after transplanting (DAT) (33 kg N ha^{-1}) and at 60 DAT (57 kg N ha^{-1}). The appropriate crops duration (transplanting to harvesting) of first and second crops were 110 and 111 d.

2.3 Water management in rice field of two systems

In CF, the water level was continuously kept at 5 cm above soil surface during the transplanting phase to before harvesting phase. In the case of AWD, it was controlled at 5 cm and was allowed to dry out naturally to 15 cm below the soil surface (IRRI's "safe AWD" recommendations) (Siopongco et al., 2013). The first cycle of dried field started at 20 DAT until the commencement of flowering. AWD was continuously flooded during flowering and grain formation stages to prevent yield reductions (Bouman et al., 2007) as shown in Figure 1. Water management of AWD in this study was incomplete (one cycle) in the first crop due to the interference of rainfall but complete (five cycles) in the second crop as shown in Figure 2. The water level of rice field under AWD was monitored by field water tube (Lampayan et al., 2014).

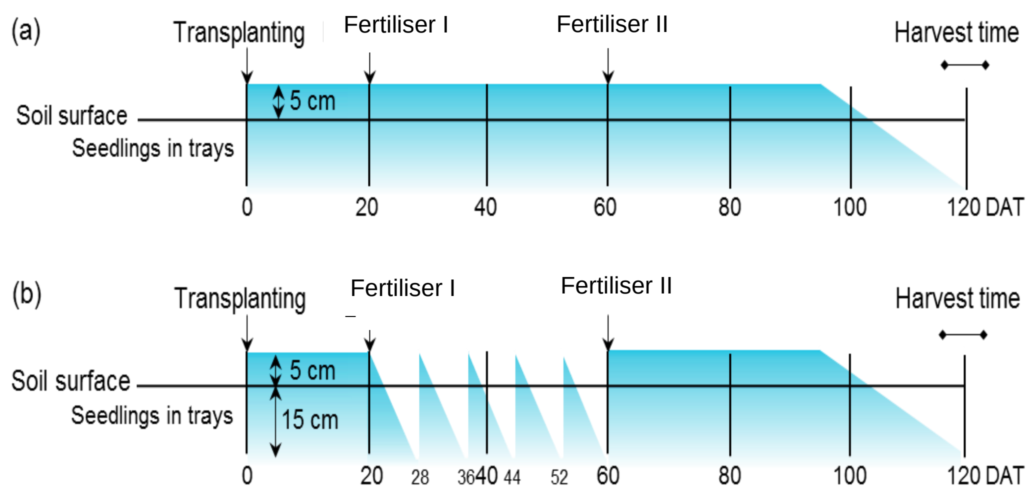

Figure 1: Schematic diagrams of CF (a) and AWD (b) water managements

2.4 Water use in rice cultivation measurement and calculation

Rice cultivation in this study used water from two main sources, the irrigation and rain. Water was irrigated by water pump (VENZ VC-200, 2HP) and the total amount of water was measured by single jet water meter (Sanwa, Model SV 15), with size of ½ inches throughout the production season. Rainfall was measured by TE 525 Tipping Bucket Rain Gauge from the Dry Dipterocarp Forest Site at KMUTT, Ratchaburi Station throughout the experiment period. Water uses in rice cultivation was calculated from the total amount of irrigation water and rainwater that increased water level in the field not exceeding 5 cm above the surface (highest level of water controlling).

2.5 Crop yield calculation

Crop yield was collected in an area of one square meter with three replications in each plot and was weighed after air dried.

2.6 Statistical analysis

The data were statistically analysed using One Way Analysis of Variance (ANOVA) and Duncan's multiple range tests of SPSS version 20. Statistical significance was determined over the 95 % confidence level at $P < 0.05$ and standard errors are given as ± SD.

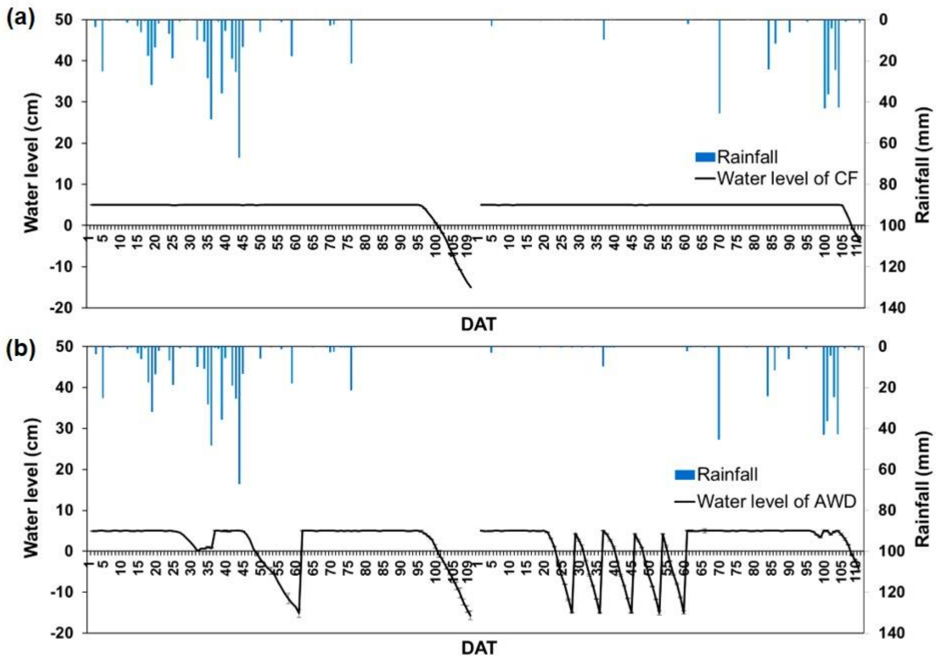

Figure 2: Water levels of two rice production seasons under CF (a) and AWD (b) water managements

3. Results and discussion

3.1 Effect of AWD water management on water use in rice cultivation

Rice cultivation under two water managements consumed water in the same pattern but in different quantities. Water consumption was low in initial and late season stages but high in mid-season stage. The maximum water was used during booting and flowering stage followed by grain formation. Rice cultivation under AWD water management reduced daily water used in tillering, and booting and flowering stages by 18.70 % and 2.48 % compared to CF while other stages were not as different as shown in Table 1. AWD reduced daily water use from the step of transplanting to harvesting by 8.13 % and from land preparation to harvesting by 7.51 % as compared to CF. It is clear that AWD reduced water used in the period of AWD cycles that occurred in these two stages. AWD implementation may require more labor because of the more scrupulous water level control than CF (Kasumov et al., 2017).

Table 1: Water use in rice cultivation per day under two water managements

Stage	Water use in rice cultivation (mm day^{-1})	
	CF	AWD
Land preparation	6.84 ± 0.80 d	6.81 ± 0.73 d
Transplanting	7.57 ± 0.18 cd	7.64 ± 0.51 cd
Tillering	9.84 ± 1.14 b	8.00 ± 1.72 cd
Booting and flowering	13.29 ± 0.87 a	12.96 ± 0.19 a
Grain formation	12.71 ± 0.84 a	12.54 ± 0.82 a
Maturity	1.79 ± 1.31 e	1.78 ± 1.42 e
Transplanting to harvesting	9.10 ± 0.75 bc	8.36 ± 1.04 bcd
Land preparation to harvesting	8.65 ± 0.77 bc	8.00 ± 1.05 cd

The results showed that AWD is a technique that can reduce water used in rice cultivation (Howell et al., 2015) due to its water input reduction (Rahman and Bulbul, 2014) by allowing the field to dry in tillering stage

(Adhya et al., 2014). Statistically, the water used in rice cultivation of AWD was not significantly less than CF. The result of this study is in accordance to the studies of Rejesus et al. (2011) and Lampayan et al. (2015) in Philippines, Ye et al. (2013) in China, Linquist et al. (2015) in USA, and Khairi et al. (2016) in Malaysia which concluded that AWD can reduce the amount of irrigation water, but the reduction percentage of this study was less than their studies.

3.2 Effects of AWD water management on plant growth

The growth of rice plant was observed by the amount of tiller per hill and the height. AWD promoted more tiller number because it allowed the field to dry in tillering stage which accelerated stronger root growth of rice plant (Richards and Sander, 2014) and as a result, increased more effective tillering (Yang and Zhang, 2010) but this was only found in complete AWD. The maximum and minimum averages of rice tiller number were found in AWD in second crop (37.65 tillers) and AWD in first crop (25.67 tillers) (see Figure 3a). Tiller number increase in AWD is in concordance to the studies of Nasir et al. (2014) in Bangladesh and Howell et al. (2015) in Nepal. In term of plant height, AWD was shorter than CF in both wet and dry seasons. The dried field of AWD caused chlorophyll concentrations to decrease because it induced the loss of chlorophylls in the leaves and affected the performance of the chlorophylls in photosynthesis (Epron and Dreyer, 1992). As a result, the rate of photosynthesis and the growth of the plant reduced (Shukla et al., 2012). The highest and lowest averages of plant height were found in CF in second crop (94.87 cm) and AWD in second crop (80.73 cm) (see Figure 3b). This is in accordance to the studies of Khairi et al. (2016) in Malaysia but different from the study of Thakur et al. (2011) in India which reported that AWD increased the height of rice plants.

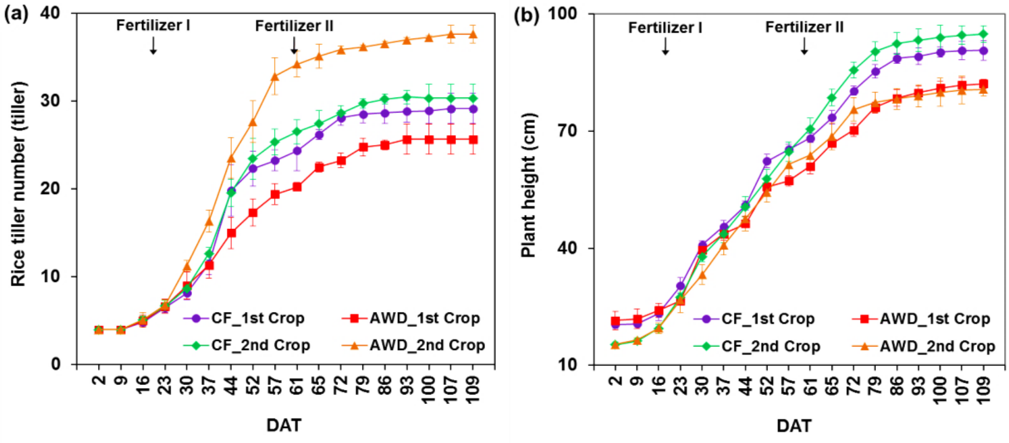

Figure 3: Tiller number (a) and height (b) of rice under two water managements

3.3 Effects of AWD water management on yield

AWD increased panicle number (significantly) and grain yield (non-significantly) of rice cultivation but it is only found in complete AWD while incomplete AWD decreased the amount of panicle and grain yield significantly as compared to CF (see Figure 4). Complete AWD increased panicle number and grain yield by 12.07 % and 2.42 % while incomplete AWD reduced panicle number and grain yield by 10.27 % and 9.12 % compared to CF. Complete AWD increased panicle number and grain yield (Rahman and Bulbul, 2014) through the increase of effective tiller number (Yang and Zhang, 2010), reduction in humdrum vegetative growth (tillers that not produce by encouraging early tillering), decreasing the angle of the topmost leaves (hence allowed more light to penetrate the canopy), modifying shoot and root activity, and altering plant hormone signaling (Davies et al., 2011). This study is in accordance to the studies in China which demonstrated that AWD increased grain yield by an average of 6.17 % (Ye et al., 2013) and 11.00 % (Zhang et al., 2009). Some studies have reported that AWD in Vietnam had no change in yield (Pandey et al., 2014) and in USA and Malaysia had decrease of yield by an average of 8.87 % (Linquist et al., 2015) and 46.15 % (Khairi et al., 2016). A major barrier to the widespread adoption of AWD is uncertainty of the amount of yield due to AWD adoption in many rice producing regions has been limited (Senthilkumar et al., 2009).

3.4 Water Productivity

AWD increased water productivity of two seasons significantly as compared to CF. It showed that at the same amount of water, rice cultivation under AWD obtained more grain yield than CF.. Water productivity of rice production in dry season was less significant than wet season as shown in Table 2 due to higher water use of dry season than wet season while grain yield of two seasons were not difference.. Water used during dry season was much higher than wet season due to higher air temperature and lower rainfall intensity. These findings are in accordance to the studies of Li and Barker (2004) in China which showed that AWD increased water productivity. Bouman and Tuong (2001) in India and Philippines also reported that water-saving irrigation increases water productivity up to a maximum of about 1.9 kg m^{-3}.

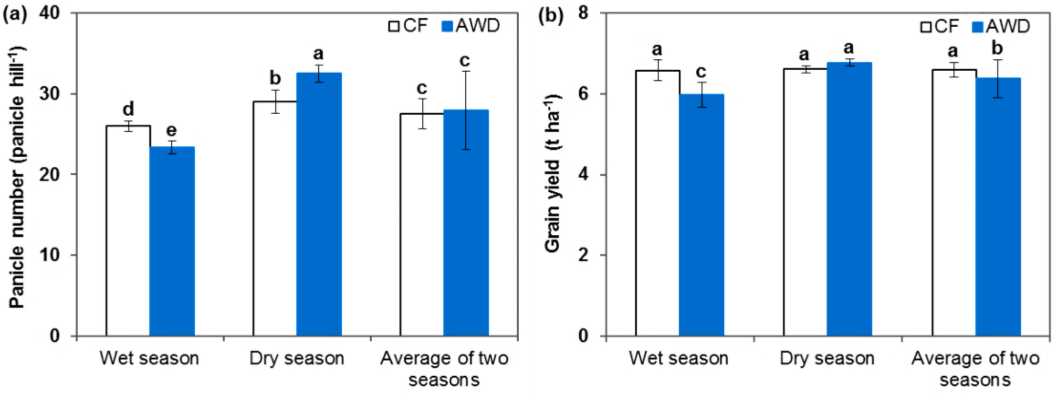

Figure 4: Panicle number (a) and grain yield (b) of rice cultivation under two water managements

Table 2: Water productivity of two rice production seasons under two water management systems

Season	Water productivity (kg m^{-3})			
	Transplanting to harvesting		Land preparation to harvesting	
	CF	AWD	CF	AWD
First crop/incomplete AWD	0.70 ± 0.03 b	0.73 ± 0.04 a	0.58 ± 0.02 e	0.60 ± 0.03 e
Second crop/complete AWD	0.62 ± 0.01 d	0.66 ± 0.01 c	0.51 ± 0.01 h	0.54 ± 0.01 g
1 y (two crops)	0.66 ± 0.01 c	0.69 ± 0.02 b	0.54 ± 0.01 g	0.56 ± 0.02 f

4. Conclusions

Alternate wet and dry (AWD) is a water management technique that can reduce water use in rice cultivation without compromising yield. Water use reduction of AWD is statistically significant in tillering stage of complete AWD as compared to CF. The benefits of AWD implementation in terms of water use reduction and yield increase can be found in areas where there are no interference of rain water in the period of tillering stage.

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