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EFFECTS OF ALTERNATE WETTING AND DRYING TECHNIQUES ON GRAIN YIELD AND WATER USE EFFICIENCY IN IRRIGATED RICE

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Abstract: The alternate wetting and drying method (AWD) is an irrigation technique to reduce the use of water in paddy fields. The effect assessment of AWD method on plant growth, yield and water management in Thailand is still in preliminary stages, and few studies have been conducted in the region. The objective of this study is to determine whether AWD method may maintain grain yield with reduced water input compared to the conventional practice of continuous flooding (CF) in northern Thailand. The implementation of water management strategies under AWD method was tested in comparison with CF. The experiment was conducted during the dry season in 2016 and 2017 in fields growing the Phitsanulok-2 rice variety in Phitsanulok irrigation project. From the results, water input to paddy plots using AWD method was less than CF by approximately 27.20 % in 2016 and 18.20 % in 2017 during the dry season. The average water productivity of paddy was at 1.19 kg/m3 and 0.89 kg/m3 for AWD and CF methods, respectively. Therefore, the AWD method may be an appropriate strategy for rice cultivation and it is an effective way to reduce excessive use of water in agriculture. The methodologies used were also adequate to support irrigation management programmes for farmers.

Keywords: Water management, irrigation, AWD, paddy yield, Phitsanulok-2 rice.

Introduction

Rice (*Oryzasativa* L.) is a staple crop in Asia. Its cultivation demands a high level of water usage, and water scarcity becomes a confounding factor that limits its agricultural productivity. Various innovations have sought to help farmers avoid water shortages and to manage scarce resources while growing rice (Dong *et al*., 2004; Liu *et al*., 2015). One technique that has been developed to reduce total water use is the alternate wetting and drying (AWD) method, which was first employed by the International Rice Research Institute (IRRI) more than 20 years ago. AWD method was developed by IRRI so that rice — despite being a semi-aquatic plant — may be grown with minimal water supply without suffering any negative yield effects. As the water level drops below soil surface, the soil is still wet enough for the rice plant to grow. AWD method consists of innovative irrigation practices to enhance water efficiency, gaining an economic advantage while also reducing environmental burdens. The method is also known as controlled irrigation or intermittent irrigation, distinct from farmers' conventional practice of continuous flooding (CF). The AWD method may also reduce the number of irrigations significantly compared with the current practice, which may reduce paddy water consumption by 25 % (Siopongco *et al*., 2013)

In areas with water scarcity, irrigation must be prudently managed to ensure successful agricultural production. The increasing incidence of water shortage requires sustainable irrigation practices to increase crop productivity and conserve resources. Therefore, crop irrigation investigations have been conducted to maximize performance, efficiency and profitability. The objective of our experiment is to evaluate the growth, yield and water productivity of irrigated rice (Phitsanulok-2) grown under different quantities of water supplied through AWD and CF methods.

Materials and Methods

Experimental Site

The study was conducted in a paddy field belonging to the Phitsanulok Irrigation Water Management Research Station in Phitsanulok province, northern Thailand (Figure 1). The site's longitude and latitude were 17° 03' 05'' N and 100° 13' 29'' E, respectively. The elevation above mean sea level stood at 47.5 m. It was influenced by the tropical monsoon weather, which comprised two seasons — the dry season from November to April, and the rainy season from May to October. The average annual precipitation was 1338 mm for 30 years between 1988 and 2017. Daily weather data were collected by an agro-meteorological station in the experimental field. The field experiment was conducted in dry season, which was also the rice growing season (December-April) of 2016 and 2017. Soil samples were drawn from a depth of around 30 cm and analyzed to determine the pH, texture, organic matter content, permanent wilting point and field capacity as indicated in Table 1.

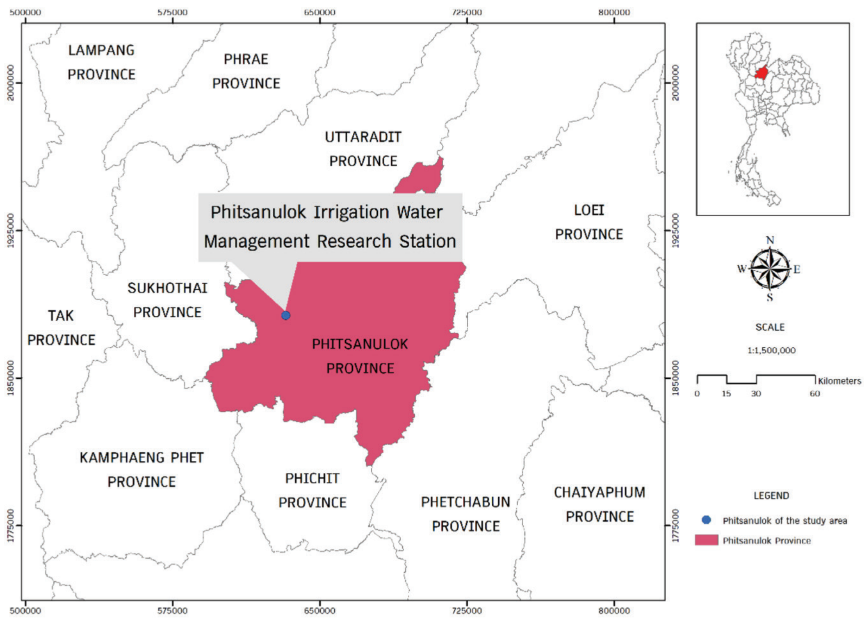

Figure 1: Location of the study area in Phitsanulok district, north Thailand

Table 1: Physico-chemical properties of the soil in the paddy field (depth 0-30 cm)

Parameter*	Value (2016)	Value (2017)
Sand (%)	8.6	8.8
Silt (%)	11.0	10.3
Clay (%)	80.4	80.9
Texture Class	Clay	Clay
pH	5.0	5.3
Organic Matter (%)	2.5	4.6
Field Capacity	40.8	40.8
Permanent Wilting Point	28.7	27.4
Available P (ppm)	2.4	3.0
Total Extractable K (ppm)	40.0	38.0

*Qualification Test by Office of Research and Development, Royal Irrigation Department, Thailand

Methods of Water Management

The experiment was repeated over seasons using randomized complete block design. The first water management method was designated AWD1, where the plot was initially flooded up to 5 cm of water. When the ponded water level dropped to -5 cm below ground level, the field was reflooded back to 5 cm. The drying and reflooding cycle was repeated the entire season and irrigation was stopped two weeks before harvest (Figure 2). In the second method designated AWD2, the plot was flooded with 5 cm water from the first day of transplanting until 25 and 45 days after transplanting (DAT). When the ponded water level dropped to -15 cm below ground level, the field was reflooded up to 5 cm for the entire season, and irrigation was stopped two weeks before harvest (Figure 3).

Irrigation methods were designed for planting the Phitsanulok-2 rice in 20 x 25 cm spacing plots by transplanting 21-day-old rice seedlings. For any given method, whenever one of the plots reached the irrigation threshold, all three plots for the same treatment would be irrigated. The individual plot size was 10 m x 22 m, and plots were separated by a 1-m wide alley. Bunds (dykes) of 30 cm in height were constructed along each side of the plots to prevent lateral water movement, and they were covered with black plastic inserted to a depth of 30 cm below the soil surface.

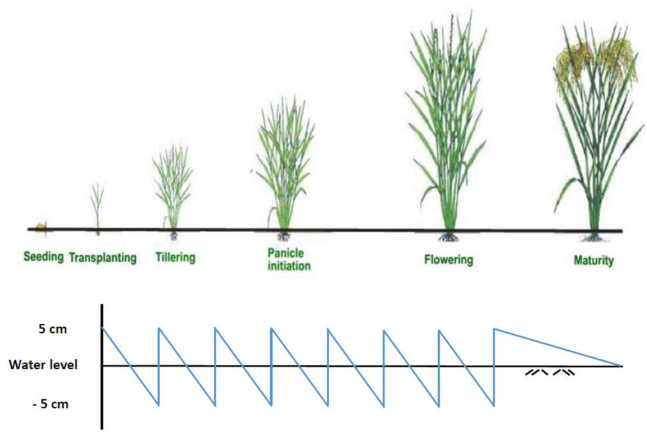

Figure 2: Schematic diagrams of water level control for field irrigation in AWD method

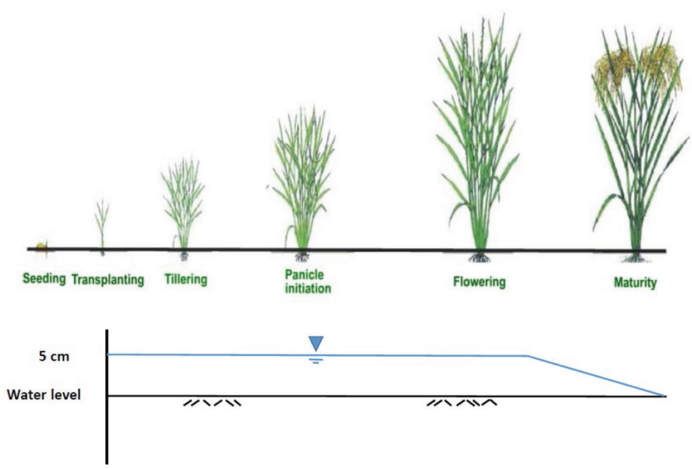

Figure 3: Schematic diagrams of water level controls for irrigation field in CF method

In both seasons, irrigation methods were carried out at 10 DAT. Field water depth was maintained at 5 cm during the first 10 DAT for the seedlings to recover while suppressing the growth of weeds. Perforated field water tubes were installed in every plot to monitor the water level below the soil surface. In CF, standing water depth of 5 cm was maintained up to 14 days before harvest. In AWD method, timing of irrigation was based on the water depth in the field water tube installed in each plot.

In both seasons, data on total water input (m^3/ha) and total water productivity (WP) (kg/m^3) were collected. Total water input included water coming from irrigation and rainfall. In both seasons, water volume input to each plot was measured using a flowmeter installed in the irrigation pipeline, whereas rainfall data was collected from a rain gauge at the Phitsanulok irrigation water management research station. WP was calculated by dividing grain yield (kg) with total water consumption (m^3) (Liang *et al*., 2016).

Results and Discussion

Growth Stage, Grain Yield and Yield Components

The interaction between water management and plant height was significant ($P<0.05$) in both experimental periods, whereas the individual effect of water management significantly affected tillering, flowering and maturity of rice plants in the dry season (Table 2). The effects of water treatments on plant height were observable in 2017, which was higher than the 2016 crop in terms of panicle initiation, flowering and maturity stages, but not the tillering stage.

In 2016, plant height was significantly higher for rice grown under the AWD method than CF at tillering stage. However, in 2017, plants grown under AWD method had significantly lower height than those grown under CF at panicle initiation and flowering stages. Plant height remained similar in transplanting stage irrespective of water management practice, but those grown under the CF method in 2017 were significantly higher than AWD at panicle initiation and flowering stage in the dry season. However, plant height was not affected by water management practice in the dry season regardless of growth stage.

The grain yield was significantly ($P\leq0.05$) different between AWD irrigation method in 2016 and 2017 (Table 3), where a higher yield was obtained in 2016. In that year, the highest grain yield was 6.53 ton/ha for rice grown under AWD method, which was higher than CF that yielded 5.90 ton/ha. In 2017, a higher grain yield was observed in CF at 5.98 ton/ha while AWD produced 5.71 ton/ha.

The AWD treatments decreased the grain yield relative to CF, the AWD treatments increased yields by 10.68 %, compared with CF plants in 2016. In 2017, the grain yield from the AWD method decreased by 4.52 % compared with CF. Although designed to boost rice yield, it was also known that AWD method could bring an opposite effect if not implemented correctly, and the drying condition was the most important factor affecting yield (Zhang *et al*., 2008; Zhang

Table 2: Summary of plant height (cm)

Growth stage	2016			2017		
	AWD	CF	P-Value	AWD	CF	P-Value
Tillering	27.56a	26.32b	0.008	18.40	18.85	0.499
Panicle initiation	45.12	47.04	0.064	49.21b	52.39a	0.024
Flowering	60.20	61.86	0.086	77.37b	84.08a	0.000
Maturity	91.49	92.06	0.580	94.26	96.13	0.136

Different lowercase letters indicate significant differences at $p \leq 0.05$ (paired t-test)

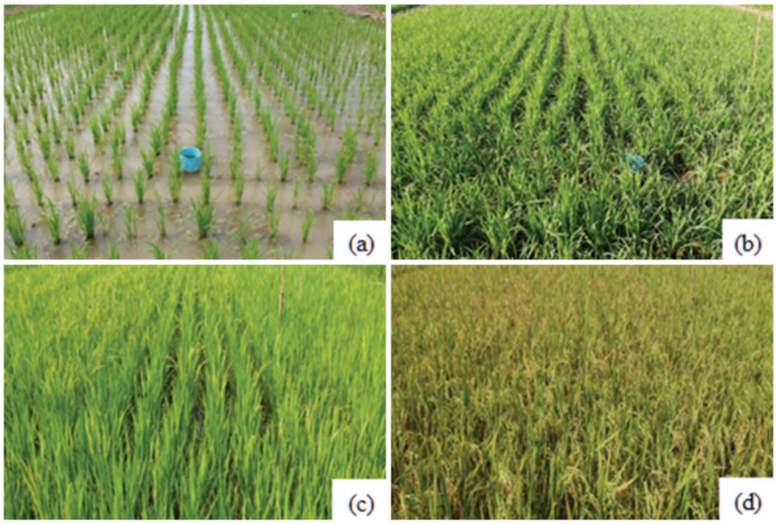

Figure 4: Growth stages of Phitsanulok-2 rice at the experimental site in (a) 2 weeks after seeding, (b) tillering, (c) formation flowering and (d) harvest

et al., 2009). Even in the same region, the results of using AWD method might vary with time and intensity of rainfall, type and amount of fertilizer used, and soil properties. Most importantly for AWD method, the discrepancies between studies might be attributed to variations in hydrological conditions and timing of irrigation applied (Belder *et al*., 2004; Yao *et al*., 2012).

In this study, the yield of AWD method being less than CF was reasonable because of the drying conditions in 2017, during which the panicle initiation and flowering stages of the rice plants had sufficient water supply. In addition, the decline in rice yields in 2017 compared to 2016 might be due to the mean maximum temperature during flowering, which was higher than 35°C. The optimum temperatures for growth and yield were between 25°C and 33°C. If the temperatures were too low or too high (below 15°C and above 35°C), the yield would be affected.

The individual effect of water management was not significant for plant/hill component in 2016, but the individual effect of water management was highly significant in 2017 ($P \leq 0.05$), when rice grown under AWD method had significantly higher plant/hill component than CF (Table 3).

Table 3: Summary of yield components and grain yield

Yield Components	2016			2017		
	AWD	CF	P-Value	AWD	CF	P-Value
Plant/ hill	35.93	35.53	0.730	36.93a	34.90b	0.039
Panicle/ hill	28.10a	24.57b	0.001	25.17	27.17	0.053
Panicle length (cm)	23.50b	24.21a	0.002	25.02	25.22	0.540
Grain/ panicle	93.37	96.05	0.646	106.10	114.80	0.343
Filled grain/ panicle	60.01	66.54	0.187	65.42	75.16	0.061
% Unfilled grain	33.93	29.51	0.146	40.68	39.70	0.871
1,000 grain weight (g)	31.40	30.52	0.083	29.34	28.71	0.126
Yield (ton/ha)	6.53	5.90	0.505	5.71	5.98	0.142

Different lowercase letters indicate significant differences at $p \leq 0.05$. (paired t-test)

In 2016, the panicle number per hill was the greatest in AWD. The panicle number in AWD method was 14.37 % greater than in CF. No significant differences were found in number per panicle among irrigation treatments in 2017. There was significant difference in panicle length of water management practices in 2016, while the individual effect of water management was not significant for panicle length in 2017. The individual effect of water management was not significant for grain/panicle in 2016 and 2017. However, the grain/panicle component was the highest in CF method.

The filled grain/panicle component was not significantly different between the irrigation treatments in 2016 and 2017. The CF method had significantly higher filled grain/panicle component than AWD, irrespective of growing season. The percentage of unfilled grain was not significantly different between irrigation treatments in 2016 and 2017. The AWD method had higher percentage of unfilled grain than CF, irrespective of growing season. The 1,000 grain weight component was also not significantly different between the irrigation treatments in 2016 and 2017. A higher grain weight was obtained in 2016 than in 2017. The individual effect of water management was not significant for yield in either year.

Water Consumption and Productivity

In 2016, with a rainfall of 735.0 m^3/ha, the AWD method's water consumption was 5,092.50 m^3/ha. The CF method water consumption was 6,995.60 m^3/ha. In 2017, with less rainfall of 395.0 m^3/ha, the water consumption in AWD and CF methods were 5,238.50 m^3/ha and 6,403.80 m^3/ha, respectively. The differences in irrigation water used between the methods were significant ($P<0.05$) as shown in Table 4. The total amount of water required for integration was closely dependent on the influence of water management techniques used in each case ($P<0.05$). The plots maintained under CF method required the highest total water input for both rice growing seasons.

The AWD method was able to reduce the amount of water required by the paddy plots. It reduced total water input by 27.20 % in comparison to CF in 2016, while the reduction was 18.20 % when compared in 2017. The AWD method was a water-saving irrigation technique that reduced the total water usage (irrigation + rainfall) of all growth stages.

The observed yield values in Table 3 were also used to compute various water productivity (WP) indicators. When the denominator was water usage amount, highest WP values were observed in AWD method for both years. WP was also observed to vary with climate, besides the irrigation method used.

A significantly higher WP of 1.28 kg/m^3 in 2016 and 1.09 kg/m^3 in 2017 was observed in rice grown under AWD method. Moreover, WP per unit of irrigation water was much higher when using the AWD method than CF. Higher WP observed during the present study was due to reduced total water input and maintaining grain yield. The results of the present study clearly indicated that WP was not only governed by water management techniques, but also environmental factors in the plants' growth

Table 4: Summary of water consumption and water productivity

Treatments	Water consumption (m^3/ha)			Water Saving (%)	Water productivity
	Irrigation water	Precipitation (millimeter)	Total		
AWD-2016	4,357.52b	735.00 (73.50)	5,092.52	27.20	1.28
CF-2016	6,260.60a	735.00 (73.50)	6,995.60	-	0.84
AWD-2017	4,843.57b	395.00 (39.50)	5,238.57	18.20	1.09
CF-2017	6,008.82a	395.00 (39.50)	6,403.82	-	0.93

Means not followed by the same letter are significantly different ($P<0.05$, t test) stages. Increased WP and better grain yield were critically important for sustainable rice production in changing climate scenarios, and this goal could be achieved with adoption of AWD irrigation method.

The AWD method was an easy-to-use technique developed for Asian farmers to reduce water input while maintaining yield in an irrigated rice production system (Liang *et al*., 2016). However, other factors came into play as studies had observed mixed results in grain yield when using the method (Belder *et al*., 2004; Yao *et al*., 2012). When early forms of AWD method were tested in tropical areas of Asia, such as in India and the Philippines, grain yield was often decreased compared with CF (Tripathi *et al*., 1986; Tabbal *et al*., 2002). In this study, this water-saving irrigation technique could be a feasible option in reducing total water input and maintaining grain yield for soil and weather conditions observed. The main constraints in wider adoption of this method included difficulty in handling, reliability and effectiveness (Liang *et al*., 2016). Extensive studies under different soil and environmental conditions were, therefore, needed for a wider acceptability of the AWD method.

Conclusion

AWD method had been successfully implemented in irrigated paddy fields to reduce water input and thereby increasing water productivity. We observed a significant reduction in total water input and higher WP when using AWD method compared with the current CF practice. WP was significantly affected by irrigation methods, which were higher in AWD than CF. Our findings highlighted that AWD irrigation method could be a sustainable way to farm rice.

However, contrasting results in yield performance do exist, therefore necessitating the evaluation of this practice in diverse soil and weather conditions. We concluded that AWD method could be recommended to rice farmers in northern Thailand as a simple and easy-to-use water-saving way to boost rice production. Wide adoption of this technology could significantly contribute to water conservation and mitigating climate change. Moreover, the role of AWD method in sustainable development of regional agriculture might need to be considered when agricultural irrigation is put forward in arid and semi-arid areas (Xi-Ping *et al*., 2006).

Saving water and change in farming practices would soon become inevitable for the survival of Thai farmers. The rational use of water resources over a large irrigation area would become an effective way to resolve challenges in sustainable farming.

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