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Water-Saving Methods in Irrigated Rice Fields in Chanthaburi, Thailand

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ABSTRACT

Khao Hawm Mae Paya Tong Dam (KHMPTD) is healthy traditional rice and an attractive rice variety grown in Chanthaburi, Thailand. Due to the increasing water scarcity for rice, there is a need to develop alternative irrigation systems using less water in producing high grain yield. The study aimed to assess grain yield of KHMPTD rice under continuous flooding and alternate wetting and drying irrigation systems with two different seedling ages of transplanted rice. The study was set out following a split-plot design in randomized complete block design. Continuous flooding (CF) and alternate wetting and drying irrigation systems when the perched water is at 10 cm below soil surface (AWD10) and at 20 cm below soil surface (AWD20) occupied the main plot treatments whereas the two different seedling ages (12-day old and 25-day old) of KHMPTD rice occupied the subplot treatments. Data gathered were grain yield, irrigation water use, water used per 1 kg of unmilled rice grain, and water productivity. The results showed that when seedlings were transplanted at 12 days, AWD10 contributed to having the highest grain yield (6.53 t/ha) without grain yield decline. With this, grain yield increased by 2% with less irrigation water use (or 43% water saving) due to only 1,044 liters of water usage to produce 1 kg of unmilled rice grain. Consequently, water productivity increased up to 83% compared with CF when seedlings were transplanted at 12 days (controlled treatment). Through multiple regression analysis, water productivity explains the 99% of the grain yield under AWD10. Therefore, AWD10 when seedlings were transplanted at 12 days is the best water-saving method for KHMPTD rice production in Chanthaburi, Thailand.

Keywords: *Alternate wetting and drying, water productivity, irrigation water use, yield, rice, seedling age*

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the major stable food in Thailand and it has been the mainstay of Thai agriculture and other Asian counties. It is also one of the most important food crops in the world and is consumed by more than three billion people [1]. The world population will grow to 8.3 billion in 2030, and 9.3 billion in 2050. Increasing demand for rice with declining resources base (land, water) is a challenging research work; it is estimated that the world demand for rice will be 533 million tons of milled rice in 2030 [2]. In 2025, approximately 10% of irrigated rice will face water scarcity [3]. Declining water availability threatens yield of the irrigated rice ecosystem; thus water-saving methods with increasing yield must be sought [4] and alternate wetting and drying irrigation system must be used [5]. By increasing water productivity, water input reduced up to 35% compared with continuous flooding, but grain yield decreased [6, 7]. Soil water is lower than saturated condition decreased rice yield [8]. Water deficit affected plant growth, flowering and grain yield by 21%, 50% and 21%, respectively [9]. Irrigation water use in the alternate wetting and severe drying irrigation regimen (AWSD) was 49.8-56.2% of that applied to the continuous flooding irrigation regimen (CF) but grain yield significantly decreased in AWSD [10]. Maximal water use is up to 5,000 liters to produce 1 kg of unmilled rice grain [11], and alternate wetting and drying (AWD20) became the interesting water saving methods with increasing yield in sandy loam soil [12]. Intermittent irrigation with alternate wetting and drying intervals (AWDI) can save a significant amount of irrigation water (28%) without reduced grain yield {7.4 tons per hectare (t/h) compared with 7.37 t/h from normal planting with ordinary water management} [13]. Early transplanting is an appropriate practice to increase grain yield in irrigated rice. Furthermore, plant growth was not affected in the nursery and by transplanting because of young seedling age at transplanting [14]. Younger seedlings and wider spacing have been observed in tillering ability, panicle length, and number of filled grains that finally contributed to higher productivity with better grain quality [13].

In Thailand, the total cultivated rice area is 11.50 million hectares with an average of 3.34 t/ha. With this, the rainfed rice ecosystem is 9.61 million hectares with an average grain yield of 2.53 t/ha whereas the irrigated rice ecosystem is 1.89 million hectares with an average grain yield of 4.14 t/ha. Khao Hawm Mae Paya Tong Dam (KHMPTD) is a healthy traditional rice variety grown in the district of Khaokitchakut in the province of Chanthaburi, Thailand [15]. KHMPTD rice is drought-tolerant. Some authors reported that its yield was between 3.1-4.4 t/ha when grown in irrigated rice ecosystem. Nowadays, this rice is becoming a famous rice variety for farmers in Chanthaburi, Thailand. The current limiting water in Chanthaburi province shows a critical condition for fresh water. Increasing rice productivity requires either the expansion of rice planting area or an increase in the production per unit area. With the limited availability of cultivated land and water resources, the most effective way to increase grain yield is by selecting the available local rice variety that is tolerant to the drought-growing condition such as KHMPTD rice variety together with the development of alternate wetting and drying irrigation methods (AWDs) that can cut down water supply for rice cultivation, and with greater grain yield potential by managing the proper seedling ages.

The study aimed to assess grain yield of KHMPTD under continuous flooding irrigation and alternate wetting and drying irrigation systems with transplanting the young seedlings at 12 days and old seedlings at 25 days.

2. MATERIALS AND METHODS

The experiment was conducted at Rice Experiment Station of Rajamangala University of Technology Tawan-Ok at Chanthaburi Campus, Chanthaburi, Thailand, from August to December 2016. The study was set out following a split-plot design [16]. Three irrigation methods: continuous flooding (CF), alternate wetting and drying when the perched water is at 10 cm below soil surface (AWD10), and alternate wetting and drying when the perched water is at 20 cm below soil surface (AWD20) occupied the mainplot treatments. Two seedling ages of KHMPTD rice occupied the subplot treatments: when transplanted by young seedlings at 12 days (S12) and by old seedlings at 25 days (S25). Six treatment combinations with 4 replications comprised of CFxS12 (a controlled treatment), CFxS25, AWD10xS12, AWD10xS25, AWD20xS12, and AWD20xS25.

In CF plots, the standing water was maintained between 2 cm and 10 cm above soil surface and it was imposed at the first day of transplanting until just 2 weeks before harvest. In AWD10 and AWD20 plots, the standing water was maintained on the first 5 days after transplanting to recover from transplanting shock and then the rice plants were subjected to AWD soil moisture condition known as AWD10 and AWD20 cycles, monitored through the installed porous PVCs' reading. In each time of irrigation, the ponded water level was at 10 cm above soil surface in AWD10 and AWD20 plots. These AWD cycles were made until the plants flowered. Then, the standing water in AWD10, AWD20, and CF plots was maintained until just 2 weeks before harvest; it was drained to stimulate the physiological maturity and eased to harvest. The prepared rice seedlings of S12 and S25 were transplanted in the sandy loam soil in CF, AWD10, and AWD20 plots at plant spacing of 25 cm x 25 cm, 1 seedling/hill. The 15-15-15 basal chemical fertilizer (46.875 kg N/ha, 46.875 kg P_2O_5/ha, and 46.875 kg K_2O/ha) was applied just a day before transplanting, and then topdressing chemical fertilizer of 46-0-0 (Urea) (or 86.25 kg N/ha) was equally split and applied in 2 stages: at tillering stage (43.125 kg N/ha) and at panicle initiation stage (43.125 kg N/ha) based on the chlorophyll meter (SPAD) readings [12]. Hand weeding was done as necessary.

At maturity stage, or 130 days after sowing, grain yield at 14% moisture content was determined from the harvest area of 5 m^2 corresponding to 32 hills per plot in a unit of ton per hectare (t/ha) basis.

The volume of rain water (14,872 m^3/ha), counted from the period of land preparation until just 2 weeks before harvest, was collected from a round concrete pipe with 120 cm in diameter and 40 cm tall and was then computed to be the volume of rain water use in the unit of cubic meter per hectare basis. The value readings of irrigation water use only (m^3/ha) were done through a flow meter connected to an electric water pump. Water used (L) per 1 kg of unmilled rice grain was computed from the ratio of the irrigation water use only per unit area to grain yield per unit area. Water productivity (WP) (kg/m^3) was computed from the ratio of the total grain yield per unit area to the total irrigation water use only per unit area.

All parameters were analyzed through statistical analysis system program. Treatments means were compared using the Duncan's multiple range test at the 0.05 probability level. Relationships of grain yield with water parameters were determined through stepwise multiple regression analysis.

3. RESULTS AND DISCUSSION

3.1. Grain yield, irrigation water use, water used per 1 kg of unmilled rice grain, and water productivity

Grain yield, irrigation water use, water used per 1 kg of unmilled rice grain, and water productivity were significantly influenced by the irrigation method and seedling age (Tables 1, 2, 3 and 4). With these, it was only AWD10xS12 that increased grain yield (6.53 t/ha) by 2% without sacrificing on grain yield with less irrigation water use (or 43% water saving) due to only 1,044 liters of water usage to produce 1 kg of unmilled rice grain and consequently water productivity (0.99 kg/m^3) increased up to 83%

compared with CFxS12, a controlled treatment. Through stepwise multiple regression analysis, the water productivity has the most significant influence on grain yield. In AWD10 plots the water productivity was the parameter that significantly determined grain yield while in S12 plots the water used per 1 kg of unmilled rice grain was the parameter that significantly determined grain yield. The multiple regression equations are as follows:

Grain yield $_{(AWD10)}$ = – 1.3589 + 4.6424(water productivity) (1) $R^2 = 0.99$*

Grain yield $_{(S12)}$ = 6.3900 – 0.0071 (water used per 1 kg of unmilled rice grain) (2) $R^2 = 0.98$*

Water productivity explains 99% of the grain yield in AWD10 as indicated in equation (1). The positive coefficient values indicate that by increasing water productivity, yield also increases. Grain yield when transplanted by S12 can be explained by the water used per 1 kg of unmilled rice grain with 98% accuracy as shown in equation (2). The negative coefficient value indicates that by reducing water used to produce 1 kg of unmilled rice, grain yield increases when transplanted by S12. Similar to Chapagain and Yamaji [13], the intermittent irrigation with AWDI can save a substantial amount of irrigation water without sacrificing on grain yield and synergistic effects of younger seedlings and wider spacing noticeable in tillering ability, panicle length, and number of filled grains that ultimately led to higher productivity with better grain quality. While the significantly minimal irrigation water use (3,081 m^3/ha) with 74% water saving under AWD20xS12 was noticed, only 525 liters of water to produce 1 kg of unmilled rice grain, and increased water productivity (1.91 kg/m^3) up to 254% but consequently 9% grain yield decreased, compared with that of CFxS12. Likewise, grain yields under CFxS25 (3.99 t/ha), AWD10xS25 (4.69 t/ha), and AWD20xS25 (4.87 t/ha) were significantly lower by 2.44 t/ha (38%), 1.74 t/ha (27%), and 1.56 t/ha (24%), respectively, than that of CFxS12 mainly due to the seedling age (S25) in CF, AWD10, and AWD20. Yet, each irrigation method with S25 had substantially higher irrigation water use and water used to produce 1 kg unmilled rice grain that resulted in the reduction of water productivity compared with S12 (Tables 1, 2, 3, and 4).

Table 1 Grain yield (t/ha)

Irrigation method (IM)	Seedling age (S)		Mean[3/]
	S12	S25	
CF	6.43[1/]a	3.99c	5.21a
AWD10	6.53a	4.69c	5.61a
AWD20	5.88ab	4.87bc	5.38a
Mean[2/]	6.28a	4.52b	

[1/]in the table of IMxS means with the different letter is significantly different (P<0.05)
[2/]in the column of S means with the different letter is significantly different (P<0.05)
[3/]in the row of IM means with the different letter is significantly different (P<0.05)

Table 2 Irrigation water use (m^3/ha)

Irrigation method (IM)	Seedling age (S)		Mean[3/]
	S12	S25	
CF	11,796[1/]b	15,447a	13,622a
AWD10	6,686d	7,837c	7,262b
AWD20	3,081e	3,453e	3,267c
Mean[2/]	7,188b	8,912a	

[1/]in the table of IMxS means with the different letter is significantly different (P<0.05)
[2/]in the column of S means with the different letter is significantly different (P<0.05)
[3/]in the row of IM means with the different letter is significantly different (P<0.05)

Table 3 Water used per 1 kg of unmilled rice grain (L/kg)

Irrigation method (IM)	Seedling age (S)		Mean[3/]
	S12	S25	
CF	1,836[1/]b	3,883a	2,860a
AWD10	1,044c	1,676b	1,360b
AWD20	525d	718d	622c
Mean[2/]	1,135b	2,093a	

[1/]in the table of IMxS means with the different letter is significantly different ($P<0.05$)
[2/]in the column of S means with the different letter is significantly different ($P<0.05$)
[3/]in the row of IM means with the different letter is significantly different ($P<0.05$)

Table 4 Water productivity (kg/m^3)

Irrigation method (IM)	Seedling age (S)		Mean[3/]
	S12	S25	
CF	0.54de	0.26e	0.40c
AWD10	0.99c	0.60d	0.80b
AWD20	1.91a	1.42b	1.67a
Mean[2/]	1.15a	0.76b	

[1/]in the table of IMxS means with the different letter is significantly different ($P<0.05$)
[2/]in the column of S means with the different letter is significantly different ($P<0.05$)
[3/]in the row of IM means with the different letter is significantly different ($P<0.05$)

As the young seedlings of Khao Hawm Mae Paya Tong Dam rice variety were transplanted at 12 days (S12), grain yield improved significantly higher by 1.76 t/ha (39%) than that of old seedlings when transplanted at 25 days (S25) (Table 1). Irrigation water use, water used per 1 kg of unmilled rice grain, and water productivity were affected by seedling age; S12 contributed to having significantly lower irrigation water use and lower water used per 1 kg unmilled rice grain with higher water productivity than S25 (Tables 2, 3, and 4). Similarly, early transplanting for rice genotypes had a faster tiller emergence by 15 days than late transplanting. Early transplanting improved grain yield, up to 10% of hybrids and IR72 when seedlings were transplanted at 7 days, and up to 78% of the new plant type when seedlings were transplanted at 14 days [17]. Likewise, younger seedlings increased leaf area and subsequently increased photosynthetic activity through increased biomass production as a major portion of photosynthates accounted for dry matter [18]. Large leaf area index (LAI) is associated with high grain yield of rice [19]. Young seedlings contributed to having more leaf area covering ground area led to low sunlight penetration on ponding water in rice fields, and consequently low evaporation of irrigated water from the rice fields hence less irrigation water use, low water used to produce 1 kg of unmilled rice grain, high water productivity. All these factors therefore contributed to having high grain yield at S12 compared with those at S25.

Grain yields under AWD10 and AWD20 were slightly higher than CF, even though their grain yields (5.21-5.61 t/ha) were not significantly different under the three irrigation methods (Table 1). Irrigation water use and water used per 1 kg unmilled rice grain were significantly influenced by the irrigation methods as AWD20 and AWD10 had less irrigation water use and less water used to produce 1 kg of unmilled rice grain than CF (Tables 2 and 3). Water productivity was influenced by the irrigation method as AWD20 gave the significantly highest water productivity followed by AWD10, compared with CF (Table 4). By increasing water productivity, grain yield slightly increased by 3-8% under AWD20 and AWD10, and irrigation water input reduced up to 47-76%, compared with CF (Tables 1, 2 and 4). Similarly, AWD increased grain yield by 15-28%, and contributed to greater water saving by 20-35%, and increased water productivity from 0.65-0.82 to 1.18-1.50 kg/m^3 after the application of AWD, while grain yield increased by 15-28% [20, 21]. Correspondingly, by keeping a significant depth of water throughout the season, it is not important for high grain yields. The water normally used in irrigated rice fields during the dry season is approximately 40-45% to keep the soil saturated for the entire growing season, without sacrificing on grain yield [22]. The increase in water productivity (1.26 kg/m^3) under AWD compared with that of CF (0.96 kg/m^3) was also cited [23]. In the same way, when maintaining a very thin layer of water at saturated soil condition, or alternate wetting and drying, it could reduce the quantity of water used by 40-70% compared with continuous shallow submergence, without sacrificing on grain yield [24, 25, 26]. Irrigation water use reduced by 20-50% for non-flooded rice compared with flooded rice, with the difference depends on rainfall, soil type and water management practices, and grain yields for non-flooded rice decreased proportionally with the reduction of water applied due to increased water stress to the rice plant [27, 28].

4. CONCLUSION

It is therefore concluded that alternate wetting and drying irrigation system when seedlings were transplanted at 12 days (AWD10xS12) contributed to having the highest grain yield (6.53 t/ha) without grain yield decline. Grain yield under AWD10xS12 increased 2% with less irrigation water use (43% water saving) due to only 1,044 liters of water used to produce 1 kg of unmilled rice grain. Consequently, water productivity increased up to 83% compared with the controlled treatment, continuous flooding when seedlings were transplanted at 12 days (CFxS12). Water productivity explains the 99% of the grain yield under AWD10.

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