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Impact of water-saving method on grain yield of rice var. Khao Hawm Mae Paya Tong Dam in irrigated fields

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Abstract This study focused on the grain yield of rice var. Khao Hawm Mae Paya Tong Dam (KHMPTD) in alternate wetting and drying when the perched water is at 20 cm below soil surface (AWD20), and at 10 cm below soil surface (AWD10), and continuous flooding (CF) irrigation methods after transplanted with 12-day old (S12) and 25-day old (S25) seedlings. There was an increase in grain yield and reduction in plant height at vegetative growth in AWD10 compared with AWD20 and CF. Grain yields in AWD20 and AWD10 were higher by 2% and 13%, respectively, than in CF. AWD20 and AWD10 can reduce irrigation water application by 74% and 47%, respectively. Less irrigation water application to produce 1 kg of unmilled rice grain in AWD20 and AWD10 contributed to having significantly higher values of water productivities with no penalty on grain yields as compared with that in CF. Through stepwise multiple regression analysis, grain yields in AWD20, AWD10, and CF can be explained by water productivities with 100% accuracy as grain yields had the positive coefficient values with water productivities. Grain yield from transplanted S12 was significantly higher by 47% than transplanted S25 due to significantly higher productive tillers per plant. Grain yields were significantly affected by irrigation method and seedling age management. Only grain yield in AWD10xS12 (8.43 t/ha) was significantly higher than in CFxS12 (a controlled treatment; 7.83 t/ha). Consequently, its shorter plants required less irrigation water application (7,623 m^3 water/ha) and less amount of irrigation water application to produce 1 kg unmilled rice grain (905 L water/kg grain), 43% water saving, and without the reduction of grain yield. This raised the water productivity up to 1.11 kg grain/m^3 water. Therefore, AWD10xS12 served as the best water-saving method to produce more rice var. KHMPTD in irrigated rice fields.

Keywords: AWD, Water saving, Seedling age, Grain yield, Rice, Water productivity

Introduction

By 2030, the estimated world demand for rice (*Oryza sativa* L.) will be about 533 million tons of milled rice (FAO, 2001). Irrigated rice has the largest

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consumption of water in the agricultural sector (Thakur *et al.*, 2014). By 2025, about 10% of irrigated rice will face water scarcity (Bouman *et al*., 2007). Even a short period of water deficit is highly sensitive to rice productivity (O'Toole, 2004). Declining water availability threatens the yield of irrigated rice ecosystem; thus water-saving methods with increasing yield must be sought (Guerra *et al*., 1998). Alternate wetting and drying irrigation method (AWD) must be used (Tabbal *et al.,* 2002). Alternate wetting and drying (AWD20) became an interesting water-saving method (fresh water) with increasing yield in sandy loam soil (Wiangsamut *et al*., 2013). By increasing water productivity, water input reduced up to 35% compared with continuous flooding, however, grain yield decreased (Borell *et al.*, 1997; Lu *et al.*, 2000). The maximal water use is up to 5,000 liters to produce 1 kg of unmilled rice grain (Cantrell and Hettel, 2004) and rice production methods require about 1,900 to 5,000 liters of water to produce 1 kg of unmilled grain (Khairi *et al*., 2015).

Transplanting 25-day old rice seedlings, or older, contributed to having a high grain yield as a result of higher tiller production. Pasuquin *et al*. (2004) reported that late transplanting delayed tiller emergence by 15 days for rice genotypes compared with early transplanting. The latter has 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. Early transplanting appears to be a relevant practice to improve yield in irrigated rice. Pasuquin *et al*. (2008) further added that plant growth was not affected in the nursery by transplanting at younger seedling age.

In Thailand, the total growing area for rice is 11.50 million hectares with an average of 3.34 tons per hectare (t/ha). The irrigated rice ecosystem is 1.89 million hectares with an average grain yield of 4.14 tons per hectare (TREA, 2019). Rice var. Khao Hawm Mae Paya Tong Dam (KHMPTD) is a healthy inbred rice variety grown in Thailand, particularly in Chanthaburi province (Lertnimitmongkol and Mongkontanawat, 2020). It is a very popular variety due to its medicinal properties i.e. antioxidants and anthocyanins. Anthocyanins are active ingredients in healing the inflammation of the muscles whereas antioxidants are active ingredients in inhibiting growth of cancer cells. Normally, rice var. KHMPTD is grown in the upland rice areas but low grain yield was obtained between 1.25-1.56 t/ha. But its grain yield increased up to 3.1-4.4 t/ha in continuous flooding fields when transplanted by 30-day old seedlings, one seedling per hill in irrigated rice ecosystem. Increasing population and market demand on milled rice var. KHMPTD alongside scarce water supply has become the main problem for farmers in irrigated fields. To solve this problem, the development of alternate wetting and drying irrigation methods using less water without declining grain yield are explored. Alternate wetting and drying (AWD) irrigation methods require less water use and total rice production can be increased by using water saved from one location to another to increase rice production. The interactive effect of AWD and seedling age on grain yield of rice var. KHMPTD was studied.

The aim of this research was to assess grain yield of rice var. KHMPTD after transplanted of seedlings at 12 days and 25 days in alternate wetting and drying (AWD) and continuous flooding (CF) irrigation methods.

Materials and methods

Experiment station, time of study, experimental design, and water management

The experiment was conducted at the rice fields of Rajamangala University of Technology Tawan-Ok at Chanthaburi Campus in Chanthaburi, Thailand, from August to December of 2016. The experiment was laid out in a split plot design (Gomez and Gomez, 1984). Three irrigation methods: AWD20 and AWD10 (alternate wetting and drying irrigation methods when the perched water is at 20 cm below soil surface and at 10 cm below soil surface, respectively), and CF (continuous flooding irrigation method) occupied the mainplot treatments. Twelve-day old (S12) and twenty five-day old (S25) seedlings of rice var. KHMPTD occupied the subplot treatments. The rice variety grew for only one season a year, between the wet and dry seasons, and seed-sowing was made in August and harvested in December due to its short-day plant characteristic (the rice plants flowered in early November and reached at physiological maturity stage in early December is ready to harvest). Six combinations (or treatments) comprised of AWD20xS12, AWD20xS25, AWD10xS12, AWD10xS25, CFxS12 (controlled treatment) and CFxS25, with 4 replications.

The standing water (ponded water level), 2-10 cm above soil surface, in AWD20 and AWD10 plots were kept for 5 days after the rice seedlings were transplanted to recover seedlings from transplanting shock. Then, the transplanted seedlings were subjected to alternate wetting and drying (AWD) irrigation cycles. The AWD cycles were made until the plants flowered and the standing water was kept until 2 weeks before harvest; then, drained to stimulate the physiological maturity to harvest while the standing water in CF plot was maintained between 2 cm and 10 cm above soil surface until 2 weeks before harvest then drained to stimulate the physiological maturity to harvest.

Rice seedlings, fertilizer management, and weed control

The 12-day and 25-day old seedlings were transplanted in the sandy loam soil in AWD20, AWD10, and CF plots at plant spacing of 25 cm x 25 cm, 1 seedling/hill. The 15-15-15 basal chemical fertilizer was applied at 312.5 kg/ha together with basal organic fertilizer (chicken dung pellets) at 1.25 t/ha one day prior to transplanting. The chemical fertilizer of 46-0-0 (Urea) was top dressed at the rate of 93.75 kg/ha at the tillering stage, and 93.75 kg/ha at the panicle initiation stage.

Plant sampling and data gathering

Grain yield at 14% moisture content, productive tillers per plant and plant height were gathered at physiological maturity at 130 days after sowing for all six treatments. The rice plant samples in the harvest area of 5 m^2 per plot were cut to determine grain yield (t/ha). Productive tillers per plant were counted in a unit of number per plant (no/plant). Plant height was measured from the plant base (soil surface) to the highest tip of the plant (cm/plant). The rainwater volume at 14,872 m^3/ha was gathered during the period of land preparation until two weeks before harvest.

Irrigation water application was determined through a water flow meter that connected with an electric water pump in the unit of cubic meter per hectare (m^3 water/ha).

Irrigation water application per 1 kg of unmilled rice grain (L water/kg grain) was computed from the irrigation water application divided by the grain yield.

Water productivity (kg grain/m^3 water) was computed from the grain yield divided by the irrigation water application.

Water saving (%) was computed following this formulation:

Water saving (%) = (irrigation water application in CFxS12 – irrigation water application in other irrigation method and seedling age management) x 100/ irrigation water application in CFxS12

Statistical analysis

Data derived from plant and water parameters were analyzed through Statistix 7 (SXW) software program. Treatment means were compared using the Duncan's multiple range test (DMRT) at the 0.05 probability level. Stepwise multiple regressions were used to determine the relationships of grain yield and water parameters.

Results

Grain yield

Alternate wetting and drying irrigation method when the perched water below soil surface is at 10 cm (AWD10) gave significantly higher grain yield than continuous flooding (CF), a conventional irrigation method. While it was slightly higher in alternate wetting and drying irrigation method when the perched water below soil surface is at 20 cm (AWD20) than in CF though their grain yields were not significantly different (Table 1). Grain yield from transplanted 12-day old seedlings (S12) was significantly higher than transplanted 25-day old seedlings (S25). Grain yields were significantly affected by irrigation method and seedling age management as grain yield in AWD10xS12 (8.43 t/ha) was significantly the highest; followed by CFxS12 (7.83 t/ha), AWD20xS12 (7.31 t/ha), AWD10xS25 (5.74 t/ha), AWD20xS25 (5.54 t/ha) and CFxS25 (4.76 t/ha) (Table 1).

Table 1. Grain yield (t/ha)

Seedling age	**Irrigation method (IM)**			**Mean**[2/]
(SA)	**AWD20**	**AWD10**	**CF**	
S12	7.31b[1/]	8.43a	7.83ab	7.86a
S25	5.54cd	5.74c	4.76d	5.35b
Mean[3/]	6.43b	7.09a	6.30b	

[1/]in the table of IMxSA means with the same letter is not significantly different
[2/]in the column of SA means with the same letter is not significantly different
[3/]in the row of IM means with the same letter is not significantly different

Productive tillers per plant

Productive tillers per plant were not significantly different in the three irrigation methods; neither was it affected by irrigation method and seedling age management (Table 2). The transplanted S12 had significantly higher productive tillers per plant than the transplanted S25.

Table 2. Productive tillers per plant (no/plant)

Seedling age	**Irrigation method (IM)**			**Mean**[2/]
(SA)	**AWD20**	**AWD10**	**CF**	
S12	9.6e[1/]	11.0e	11.2e	10.6a
S25	7.8e	8.4e	8.0e	8.1b
Mean[3/]	8.7a	9.7a	9.6a	

[1/]in the table of IMxSA means with the same letter is not significantly different
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[3/]in the row of IM means with the same letter is not significantly different

Plant height

Plant height in AWD10 was significantly shorter than in CF and AWD20 while it was not significantly different between CF and AWD20 (Table 3). Plant height of trantimsplanted S12 and S25 were not statistically different. Plant height was influenced by irrigation method and seedling age. AWD10xS12 had significantly the shortest plant height of 137.2 cm/plant, while the other treatments ranged from 144.1-158.2 cm/plant (Table 3).

Irrigation water application

Irrigation water application in AWD20 and AWD10 was substantially lower than in CF. Irrigation water application for transplanted S12 was significantly higher than transplanted S25. There was no interaction between irrigation method and seedling age on irrigation water application (P>0.05) (Table 4).

Table 3. Plant height (cm/plant)

Seedling age (SA)	**Irrigation method (IM)**			**Mean[2/]**
	AWD20	**AWD10**	**CF**	
S12	152.0a[1/]	137.2b	158.2a	149.1a
S25	151.0ab	150.1ab	144.1ab	148.4a
Mean[3/]	151.5a	143.7b	151.2a	

[1/]in the table of IMxSA means with the same letter is not significantly different
[2/]in the column of SA means with the same letter is not significantly different
[3/]in the row of IM means with the same letter is not significantly different

Table 4. Irrigation water application (m^3 water/ha)

Seedling age (SA)	**Irrigation method (IM)**			**Mean[2/]**
	AWD20	**AWD10**	**CF**	
S12	3,628e[1/]	7,623e	13,390e	8,214a
S25	3,623e	6,818e	13,094e	7,845b
Mean[3/]	3,626c	7,221b	13,242a	

[1/]in the table of IMxSA means with the same letter is not significantly different
[2/]in the column of SA means with the same letter is not significantly different
[3/]in the row of IM means with the same letter is not significantly different

Irrigation water application per 1 kg of unmilled rice grain and percent water saving

The values of irrigation water application per 1 kg of unmilled rice grain were affected by irrigation method and seedling age. AWD20xS12 showed significantly the lowest amount of irrigation water application to produce 1 kg of unmilled rice grain followed by AWD20xS25, AWD10xS12, AWD10xS25, CFxS12 and CFxS25, respectively (Table 5). AWD20xS12, AWD20xS25, AWD10xS12 and AWD10xS25 had substantially high water saving (43-73%) except CFxS25 (-2%) compared with CFxS12 (controlled treatment) (Table 6). It was only in AWD10xS12 that had less irrigation water application (water saving by 43%) to produce 1 kg of unmilled rice grain and grain yield increased by 8% (Tables 1, 5, and 6).

Water productivity

Water productivity was significantly different in the three irrigation methods. It was significantly the highest in AWD20; followed by AWD10 and CF, respectively (Table 7). The transplanted S12 had significantly higher water productivity than the transplanted S25. Water productivity was influenced by irrigation method and seedling age management (Table 7). Significantly, the highest water productivity was in AWD20xS12; followed by AWD20xS25, AWD10xS12, AWD10xS25, CFxS12 and CFxS25, respectively (Table 7). It was only in AWD10xS12 that had less irrigation water application and increased water productivity up to 1.11 kg grain/m^3 water without the reduction of grain yield (Tables 1, 4, and 7).

Table 5. Irrigation water application per 1 kg unmilled rice grain (L water/kg grain)

Seedling age	**Irrigation method (IM)**			**Mean[2/]**
(SA)	**AWD20**	**AWD10**	**CF**	
S12	498e[1/]	905d	1,712b	1,038b
S25	656e	1,200c	2,757a	1,538a
Mean[3/]	577c	1,053b	2,235a	

[1/]in the table of IMxSA means with the same letter is not significantly different
[2/]in the column of SA means with the same letter is not significantly different
[3/]in the row of IM means with the same letter is not significantly different

Table 6. Water saving (%)

Irrigation method and seedling age management	**Water saving [1/] (%) compared with CFxS12**
AWD20xS12	73
AWD20xS25	73
AWD10xS12	43
AWD10xS25	49
CFxS25	-2

[1/] in the column of water saving with the positive values mean the irrigation water application is lower than that of CFxS12 while the negative value means the irrigation water application is higher than that of CFxS12.

Table 7. Water productivity (kg grain/m^3 water)

Seedling age (SA)	Irrigation method (IM)			Mean[2/]
	AWD20	AWD10	CF	
S12	2.02a[1/]	1.11c	0.58e	1.24a
S25	1.53b	0.85d	0.37e	0.92b
Mean[3/]	1.78a	0.98b	0.48c	

[1/]in the table of IMxSA means with the same letter is not significantly different
[2/]in the column of SA means with the same letter is not significantly different
[3/]in the row of IM means with the same letter is not significantly different

Discussion

In AWD10, there was an increase in grain yield (7.09 t/ha) with reduction in plant height (143.7 cm/plant) at vegetative growth for rice var. KHMPTD compared with AWD20 and CF. Grain yield in AWD10 was higher by 13% than in CF due to the former gave heavier grain weight and higher number of filled grains per panicle (data not shown). The productive tillers per plant in the three irrigation methods were similar. Likewise, Yang *et al.* (2017) reported that perched water at 10 to 15 cm below the soil surface could contribute to increase grain yield and water use efficiency (WUE). Increases in grain yield and WUE under moderate AWD are mainly due to reduce redundant vegetative growth; improve canopy structure and root growth; elevate hormonal levels, in particular increases in abscisic acid levels during soil drying and cytokinin levels during rewatering; and enhance carbon remobilization from vegetative tissues to grains. Consequently, grain yield increased under AWD10. The productive tillers of rice var. KHMPTD in AWD10 (9.7 no/plant) was slightly higher than in AWD20 (8.7 no/plant) and in CF (9.6 no/plant) although their productive tillers per plant were not significantly different. This is in agreement with Song *et al*. (2018) and Zhang *et al*. (2009) who reported that grain yield in AWD was maintained or increased; depending on an increase in productive tillers (Yang *et al.*, 2017). In AWD10, the moderate irrigation water application (7,221 m^3 water/ha) with 47% water saving and the intermediate amount of irrigation water application to produce 1 kg of unmilled rice grain (1,053 L water/kg grain) contributed to having an increase in water productivity up to 0.98 kg grain/m^3 water and thus the significantly highest grain yield (7.09 t/ha) compared with that in CF. In AWD20, minimal irrigation water application (3,626 m^3 water/ha) or 74% water saving and the lowest irrigation water application to produce 1 kg of unmilled rice grain (577 L water/kg grain) contributed to having significantly the highest value of water productivity (1.78 kg grain/m^3 water) and grain yield (6.43 t/ha) increased by 2% compared with that in CF. Through stepwise multiple regression analysis, grain yields in AWD20, AWD10, and CF can be explained by water productivities with 100%

accuracy as grain yields had the positive coefficient values with water productivities. This means that by increasing water productivity, grain yield also increases. Zhang *et al.* (2009) similarly cited that an AWD method can reduce irrigation water application by 35%. In contrast, maximal irrigation water application (13,242 m^3 water/ha) and the highest amount of irrigation water application to produce 1 kg unmilled rice grain (2,235 L water/kg grain) with the significantly lowest grain yield (6.30 t/ha) in CF resulted in the significantly lowest water productivity (0.48 kg grain/m^3 water). Hence, alternate wetting and drying irrigation methods (AWD10 and AWD20) are better water-saving methods rather than continuous flooding (CF).

Grain yield from transplanted S12 was significantly higher by 47% (2.51 t/ha) than that of transplanted S25 due to significantly higher productive tillers per plant. Productive tillers per plant were consistently higher for transplanted young seedlings (S12), with a difference as large as 31% between transplanted S12 (10.6 no/plant) and transplanted S25 (8.1 no/plant). Pasuquin *et al.* (2008) reported that transplanted older seedlings induced a delay in the onset of linear dry matter accumulation and tiller emergence. The delay also reduced maximum tiller number and delayed maximum tillering hence promoting early tiller emergence as a response to transplanting young seedlings increased grain yield. However, plant height for rice var. KHMPTD was not affected by transplanted S12 and S25 as its plant height in both seedling ages was similarly ranged from 148.4-149.1 cm/plant. Moreover, the rice plants from transplanted S12 contributed to having significantly higher grain yield (7.86 t/ha) with less amount of irrigation water application by 48% to produce 1 kg of unmilled rice grain (1,038 L water/kg grain) which led to significantly higher water productivity (1.24 kg grain/m^3 water) than transplanted S25 (5.35 t/ha, 1,538 L water/kg grain, 0.92 kg grain/m^3 water).

Grain yield was influenced by the irrigation method and seedling age. Only grain yield in AWD10xS12 for rice var. KHMPTD was significantly higher than that in CFxS12, a controlled treatment. Significantly, the shortest plant height in AWD10xS12 did not affect its grain yield. Due to the assimilates translocated to the development of the roots rather than shoots during vegetable growth stages especially at tillering stage and stem elongation period, resulted in shortened plant height. At flowering and grain filling stages, shorter plants in AWD10xS12 had a faster translocation of assimilates from rice leaves and storage organs (i.e. stems) to grains. This resulted in heavier grain weight and higher number of filled grains per panicle (data not shown). Consequently, the highest grain yield of 8.43 t/ha was obtained in AWD10xS12 as compared with those taller plants among the rest of treatments. Moreover, shorter plants required less irrigation water application (7,623 m^3 water/ha) and less amount of irrigation water application to produce 1 kg unmilled rice grain (905 L water/kg grain) resulted in maximal grain yield in AWD10xS12 which raised water productivity up to 1.11 kg grain/m^3 water. This result agreed with Yamazki and Harada (1982) who reported that throughout the whole growth period of plants, the crown roots with abundant branched laterals contributed to the growth and development of plants and finally grain yields, by their activity to absorb water and mineral salts in soil. Grain yield of 7.31 t/ha in AWD20xS12 was slightly lower than that of 7.83 t/ha in CFxS12 although their grain yields were not significantly different from each other due to their similar number of panicles per plant, grain weight and number of filled grains per panicle (data not shown). Grain yield in AWD20xS12 had a tendency to decrease when the irrigation water application was at 3,628 m^3 water/ha compared with CFxS12 at 13,390 m^3 water/ha. Less irrigation water was applied to produce 1 kg of unmilled rice grain at 498 L water/kg grain in AWD20xS12 increased water productivity up to 2.02 kg grain/m^3 water but grain yield decreased by 7%. Grain yields in AWD20xS25, AWD10xS25, and CFx25 were significantly affected by irrigation method and seedling age management, especially when all three irrigation methods (AWD20, AWD10 and CF) matched the transplanted S25 (old seedling age), compared with grain yield in the controlled treatement (CFxS12). Significantly, the lowest grain yield of 4.76 t/ha in CFxS25 was mainly due to low productive tillers per plant, number of panicles per plant, grain weight and number of filled grains per panicle (data not shown). Its significantly highest amount of irrigation water application to produce 1 kg of unmilled rice grain (2,757 L water/kg grain) led to the lowest water productivity (0.37 kg grain/m^3 water) hence grain yield decreased.

Therefore, AWD10xS12, or the alternate wetting and drying irrigation method when the perched water below soil surface is at 10 cm (AWD10) matched the transplanted S12 (young seedling age) management for rice var. KHMPTD, can serve as the best water-saving method to produce more rice with less irrigation water application (43% water saving) in irrigated rice fields.

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