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Effect of Different Water-Saving Irrigation Methods for Rice Cultivation, Case Study in Cambodia

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Abstract: *The increasing population and the need for more food have made demands on water resources due to crop production in Cambodia. Rice (Oryza sativa. L) is widely cultivated in Cambodia, but it consumes considerably more water than any other crop. In the context of water scarcity due to global climate change and limited water sources, rice cultivation in Cambodia has been worsened by drought and no water for irrigation. the strategies for preventing the overuse of safe water resources for agriculture is to increase agricultural productivity by reducing the amount of irrigation water with a slight reduction or maintaining the yields. It requires irrigation management to change from traditional irrigation. This study aims to evaluate the effect of different water-saving methods to define suitable methods for local rice in the dry season at CARDI, Cambodia. The experiment was split-plot based on a randomised complete block design with 3 treatments and 3 replications. The treatments were conventional irrigation (CK), Shallow-deep-Shallow irrigation (S), and Shallow and Frequent irrigation (Q). The result of this study showed that Shallow-deep-shallow (S), Shallow and Frequent significantly improved water saving by 32% to 53% over CK ($p < 0.05$). Water productivity (WP) ranged from 0.61 to 0.89 Kg/m3. However, the yield of rice showed insignificant variation in terms of rice yield, 1000-grain yield, and also for its yield components measured such as plant height ($P> 0.05$) compared to CK treatment and the average yield of rice ranged from 3.2 tons/ha, 3.3 tons/ha, and 3.8 tons/ha in Q, S, and CK. The results showed that less water can be used to produce a similar yield of rice under water-saving irrigation practices (S & Q) compared to the conventional method (CK). Adopting water-saving irrigation (Q) produced an acceptable rice yield with the highest water productivity among the irrigation practices—however, future research needs to be conducted to improve rice yield by choosing resistant rice with pest and stemborer disease and improve fertilizer application. The findings are significant for regions experiencing water shortages, providing vital information to policymakers, farmers, and agricultural departments.*

Keywords: Grain yield, Irrigation, Rice, Water saving, Water productivity

1. INTRODUCTION

Cambodia is a developing country that will face almost double population growth from its current 14.4 million in 2014 to between 20.4 and 27.4 million by 2050 [1]. The increase in population will lead to an increase in agricultural production for enough food supply needs. Agriculture is among the mainstays of Cambodia's economy and it contributed to over 25 % of the total GDP, rice is a major crop and the agricultural's backbone. It is grown by more

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than 80% of Cambodian farmers. The cultivation of rice by smallholder farmers is based on conventional methods, which utilize simple tools and techniques to cultivate small paddy fields. Traditional farming practices require farmers to irrigate paddy fields constantly. The average yield of rice in Cambodia was around 3.0 ton ha^{-1}, which is a low level compared to China, Vietnam, and Myanmar with 6.5, 5.3 and 4.1 ton ha^{-1}. In Cambodia, the total cultivated agricultural land area occupies 3.7 million hectares. Rice cultivation dominates approximately 76% of this land, while the remaining 24% is allocated to the cultivation of various other main crops including cassava, maize, rubber, soybean, mungbean, sugar cane, and vegetables [2]. Cambodia has a tropical monsoon climate having two distinct seasons in the year, a rainy season (from May to mid-November) and a dry season (from mid-November to April) with long periods of dry days without rain [3]. During the rainy season, agriculture is heavily based on rain-fed production [4]. Only 16 % of the total cultivated land is irrigated during the dry season [4]. At the same time, rice cultivated in the dry season where there is water available for irrigation, farmlands have the potential to diversify into a high yield of rice compared to the rainy season [5].

Rice cultivation in Cambodia faces some significant constraints including the effects of climate change such as flooding and drought and reliance on traditional technology. Predominantly, Cambodian agriculture is characterized by small-scale farms with sizes that vary from 0.5 to 4.3 ha [4] and low levels of technology and education due to the side effects of the Khmer Rouge Civil War limited access to education facilities and poor institutional management in remote rural areas [6]. The farmers share their traditional irrigation practices for rice cultivation from generation to generation without going to training schools . For conventional practices, a rice paddy field needs to submerge all the stages of rice which consumes much water. On the other hand, regional and seasonal water shortages caused by drought and future climate change scenarios will make water shortages more severe and threaten rice production in Cambodia. As reported by Cambodia's Second National Communication, Cambodia will be exposed to increasing drought risk under future climate change by 2025 and 2050, prolonged drought has been considered one of the main affecting factors that limit rice planting areas. Furthermore, the consequence of using the conventional flooded method, rice is associated with methane (CH_4) emission, which accounts for 11 % of the total global amount produced by humans. Therefore, the response to climate change and the target to limit greenhouse gas emissions, climate-resilient agricultural technologies and water-saving methods are crucial to farmers in order to replace conventional flood irrigation, several water-saving irrigations (WSI) know-hows have been created and spread, including alternate wetting and drying, soil-saturated cultivation, drip irrigation, bed-furrow base irrigation, and non-flooded mulching cultivation [7]. In a previous study, the water-saving method saved water by 20% to 26% and increased yield by 2% to 10% Compared to the conventional method [8]. To address the issue that has been mentioned above, a proper irrigation technique is required. A promising solution to rice cultivation with water scarcity is a water-saving method such as Shallow-deep-shallow (S), and Shallow and Frequent (Q) designed to irrigate paddy fields when needed, to save water. Our study aims to evaluate the effect of different water-saving methods to define suitable methods for local rice in the dry season at an experiment site in CARDI, Cambodia.

2. METHODOLOGY

2.1 Study Area

The experiment was conducted at the Cambodian Agricultural Research and Development Institute (CARDI), Phnom Penh, Cambodia. With latitude and longitude were 11° 28' 37.31" N and 104° 48' 29.19" E. CARDI is located in Prateah Lang Commune, Dangkor district, 20 kilometers south of Phnom Penh, in the dry season from 11th January to 19th April. The soil composition is Prateah lang with 62 % Sand, 25 % silk, and 13 % Clay (0 to 30 cm), with a bulk density of soil 1.66 g/cm^3 (Table1) The climate in the study area is a tropical climate with an average monthly minimum and Maximum air temperature of 24℃ and 34℃ during the planting period. The total average daily precipitation is 0.57 mm, mainly from January to April. the daily temperature and rainfall during the growing period in 2023 are represented in (Fig.1). The total experiment size is 46.6 m × 16.2 m and was randomized and split into nine blocks with three different treatments and three replications.

Table1.Soil Characteristics in experiment size (0-30 cm)

Characteristic	Value
Texture (%)	
Sand	62
Silt	25
Clay	13
BD (g/cm^3)	1.66

The graph below displays the daily temperature and rainfall during the growing period.

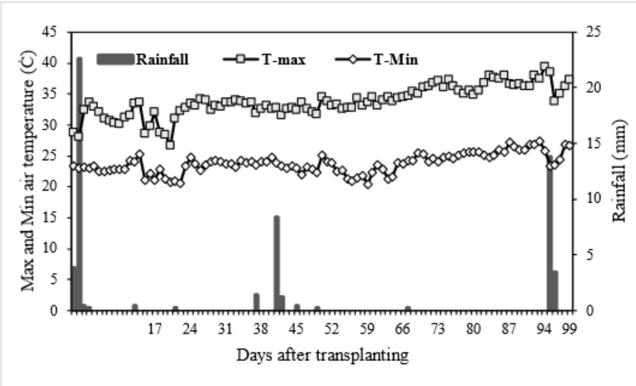

Fig.1. Daily temperature and rainfall during the growth period.

2.2 Treatment design

To save water and improve irrigation practices, this study conducted an experiment on irrigation scheduling by controlling the method of field water, given that most of Cambodia's rice planting and irrigation practices rely on traditional flooding irrigation, which consumes a significant amount of water. The field experiment was a randomized block design in three replications and consisted of three treatments, namely: (1) Conventional irrigation (CK), (2) Shallow-deep-Shallow irrigation (S), (3) Shallow and Frequent irrigation (Q) (Fig 2). The 15 m × 4.8 m replication plot sizes were separated by 30 cm-wide soil ridges covered with plastic film to inhibit water and nutrient exchange between plots. Three irrigation regimes with different water controls in different growth stages were included in these experiments, corresponding to seven growth stages of rice: regreening, early tillering, late tillering, jointing-booting, heading-flowering, milk, and yellow repining (Table. 2). Irrigation was initiated when the water depth reached the lower limit, and excess rainwater was drained to the maximum storage height. Water percolation was achieved by controlling the amount of surface water draining. For the CK treatment, the field was continuously flooded with 50 mm of surface water at the regreening and early tillering stages, 70 mm at the late tillering stage, and 100 mm at the jointing-booting, heading-flowering, and milk stages. The water was drained out at the yellow repining stage, and the soil water content was maintained at 70% (Fig 3). For the shallow-deep-shallow treatment (S), the water level was maintained at 30 mm during the regreening and early tillering stages. At the late tillering stage, the field was drained, and the soil water content was lowered to 70%. The field was then flooded with 70 mm of water at the jointing-booting and heading stages and with 30 mm of water at the milk stage. At the yellow ripening stage, the field was drained again, and the soil water content was maintained at 70%. The water level was allowed to fluctuate between 10 mm and 70 mm throughout the S regime (Fig 4). For the shallow and frequent irrigation treatment (Q), the water level was maintained at 30 mm throughout all growth stages, except for the late tillering and yellow ripening stages, when the field was drained, and the soil water content was reduced to 70%. During the late tillering stage, the surface water was removed from the rice crop for 5 to 7 days, allowing the soil to dry, crack, and re-aerate. The water level was allowed to fluctuate between 10 mm and 30 mm in the Q regime, meaning that water was reapplied to the field when the water level reached 10 mm (Fig 5).

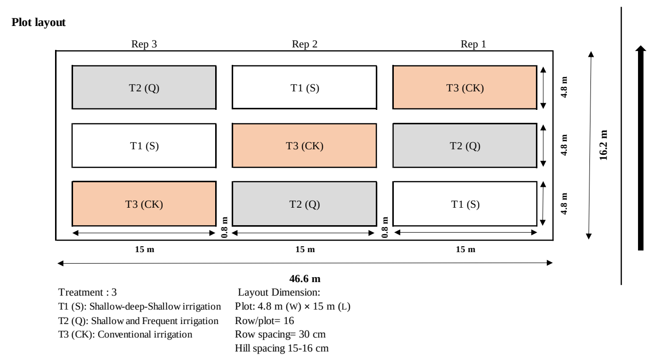

Fig 2. Experimental plots arranged in CARDI and placed under three water regimes.

Table. 2. Presents the crop calender of three treatments.

Treatment	Growing Stage	Date
	Sowing	19- Dec to 11- Jan
	Transplanting	11-Jan
	Regreening	20 -Jan to 29- Jan
	Early tillering	30-Jan to 5 -Feb
S Q CK	Late tillering	6-Feb to 12-Feb
	Jointing-booting	13-feb to 19-Mar
	Heading-flowering	20-Mar to 27-Mar
	Milk	28-Mar to 7-Apr
	Yellow ripening	8-Apr to 19-Apr

2.3 Crop meansurement

Crop samples for biomass and canopy cover were taken twelve times from transplanting onward for all treatments. The sampling days were 17, 24, 31, 38, 45, 52, 59, 66, 73, 80, 87, and 94 DAT (days after transplanting). At each sampling, the above-ground biomass was collected destructively by random five hills per plot (each hill consisting of five to ten rice plants). The samples were taken to the laboratory and rinsed with water. The roots were removed, and all the samples were input into the oven for deactivation of enzymes at 70 ℃. Keep it in the oven for two days until it is a constant weight. The above-ground biomass of rice was sampled based on [9]. Canopy covers were collected with a smartphone (Samsung Galaxy Note 20., Korea) at three points per plot. The format picture at a resolution of 1080 × 2040. The images were collected between 9:00 and 11:0 a.m. every week from early tillering to ripening under clear-sky conditions. Color digital images of paddy fields over the experimental plots were taken vertically at a constant height of 2 m and area of 1 m2. Canopy covers were sampled, followed [10].

2.4 Crop Management and Monitoring

Land preparation in all the treatments was done by ploughing and levelling the soil under dry conditions. The rice variety is Sen Kror-ob 01. It was planted on 11th January and harvested on 19th April for all the treatments in 2023. Rice transplanted with spacing: row spacing 30 cm, and plant spacing 15 cm. The fertilizers were applied two times, a basal application before planting around 555 g/plot of Urea, 655 g/plot of DAP, and 960 g/plot of KCL. The second time was applied as Urea at a 555 g/plot rate during the panicle initiation.

The vertical rulers were used to monitor and measure the value of the water level in the plot site. Plastic sheets were installed in the bunds down to a depth of 20 cm at the location to prevent seepage between plots with different water regimes. In all sites, the water level was regularly monitored manually; when the water dropped to the critic S, Q, and CK levels, irrigation took place. The plots were irrigated following the stage of rice. Water needs to be drained from the plot site if there has been rain and the water level is higher than 80 mm.

Then, the amount of water irrigated was calculated by dividing the measured values of the water level in the field and the irrigated area.

$$I_t = \frac{I}{A} \qquad \text{(Eq. 2)}$$

With I_t being the total irrigation (m^3/ha), I being the irrigation amount (mm), and A being the irrigated area.

The water was input in all stages of rice for empirical control treatment. However, for the treatment, Q and S excepted to dry field during the late tillering stages of rice. In addition, on February 28, the plot of rice needs the drained water for stemborer pesticide. The total irrigation amounts were 533, 366, and 790 mm in the S, Q, and CK plots, respectively. All the treatments were subjected to the same pesticide and fertilizer application rate.

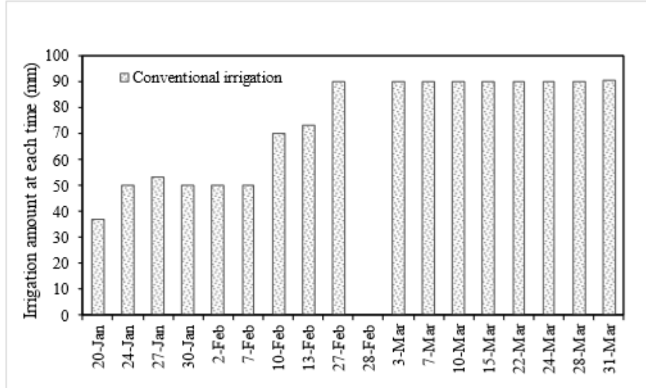

Fig 3. Irrigation amount (mm) for Conventional treatment (CK).

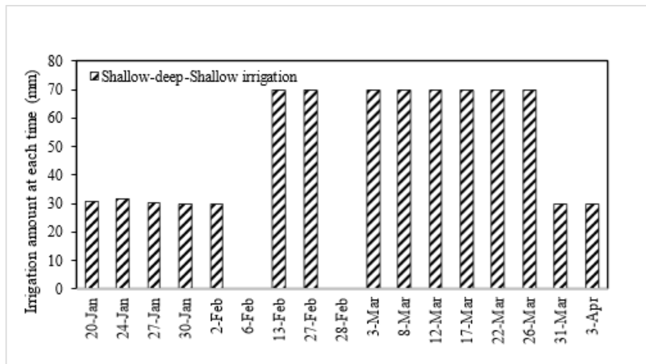

Fig 4. Irrigation amount (mm) for Shallow-deep-Shallow treatment (S).

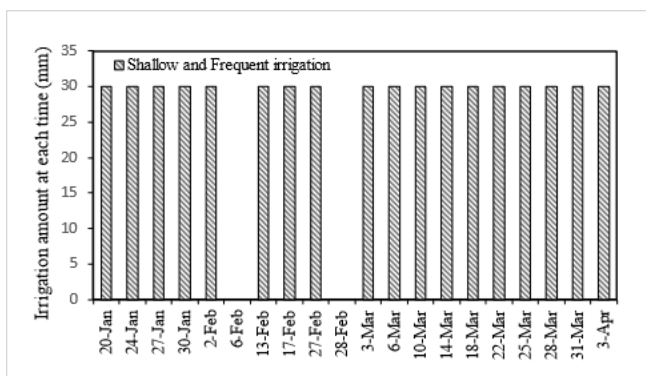

Fig 5. Irrigation amount (mm) for Shallow and Frequent treatment (Q).

2.5 Yield Calculation

A $24m^2$ rice plant at physiological maturity was harvested for yield determination. Grain yield was adjusted to 14% moisture content using the formula:

$$Yield = GW \times (100 - GMC)\% / (100 - 14)\% \quad \text{(Eq.3)}$$

Where:
GW = Grain weight (kg)
GMC = Grain moisture content (%).

Plant height was measured from the one selected hill of each plot, and then, a total of five hills of five replicates for each treatment were averaged. Before heading, the height of each plant was the height from the soil surface to the highest leaf tip of each hill, and the height of each plant, after heading, was the height from the soil surface to the highest panicle top. After the crop was harvested, selected hills of rice plants were collected. Dry weight of 1000 grains that were collected from the samples of filled grains per treatment were obtained by drying at 70 ºC in the oven for 72 h to constant dry weight.

2.6 Water productivity and Water saving

Water productivity was calculated as grain yield divided by the total water input from rainfall and irrigation:

$$WP = \frac{G}{I_t} \quad \text{(Eq.4)}$$

Where:
G = Grain yield (kg)
I_t = Total amount of water input (m^3)

Water saving was determined with reference to the irrigation water and calculated as the difference in irrigation under the two irrigation regime divided by the irrigation water applied under the CK regime as shown in Equation (5). The number of irrigations was determined by calculating mean number of all irrigations for each plot.

$$Water\ saving = \frac{I_{CK} - I}{I_{CK}} \quad \text{(Eq. 5)}$$

Where I_{CK} is the water applied in CK, and I is the water applied in Water saving S or Q.

2.7 Statistical analysis

All statistical analyses were conducted using Excel (Microsoft excel 2019). A one-way analysis of variance (ANOVA) was performed to assess the effect of water input (water saving irrigation) and the differences among treatments that enhanced all the variable describing rice growth and yield. All effects and differences were statistically significant, followed P-value < 0.05.

3. RESULTS AND DISCUSSION

3.1 Variation of plant height

The plant height increased rapidly during the tillering stage and, then, grew slowly during the middle and late tillering stages when the vigorous took place. The plant height started increasing again during the jointing-booting stage and reached the highest value during the heading-flowering stage. The plant height was less variable and tended to be stable during the milk stage and yellow ripening stage, which coincided with the time of the reproductive stage (Fig.6). The average height of rice plants receiving empirical as control treatments ranged from 32.1 to 105.9 cm, and for plants receiving Shallow-deep-Shallow treatments (S), it ranged from 30.1 to 107 cm, and for the average height plant receiving from the Sallow and Frequent treatments ranged from 30.4 to 103.1 cm. The difference was not significant (p > 0.05) except at 66 and 73 days after transplanting (DAT) (Table.3 & Table.5).
The highest plant height is in treatment (S). Similarly, result were reported by [11], under water saving method could maintain or increase rice plants height.

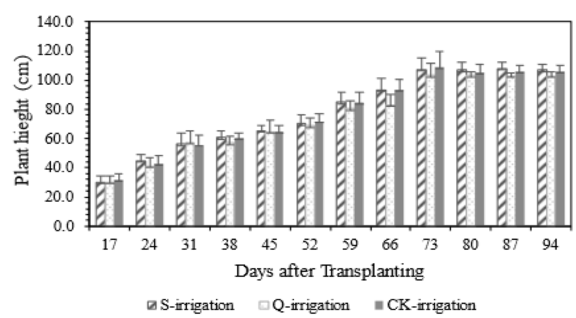

Fig.6. Variation of Plant height in each growth period

Table.3. Statistical analysis for plant height for all treatments with different DAT (a).

Treatment	Days After Transplanting (DAT)					
	17 DAT	24 DAT	31 DAT	38 DAT	45 DAT	52 DAT
S	30.1 ± 3.13[ac]	44.7 ± 1.13[ac]	56.2 ± 2.36[ac]	60.7 ± 2.36[ac]	65 ± 3.41[ac]	73.8 ± 4.46[ac]
Q	30.4 ± 1.44[ab]	40.9 ± 1.22[ab]	57.3 ± 1.80[b]	57.1 ± 1.80[ab]	66.1 ± 4.46[ab]	65.6 ± 4.08[ab]
CK	32.1±0.98[a]	42.6 ± 2.94[a]	55.7 ± 1.02[a]	60.5 ± 1.02[a]	67.8 ± 2.28[a]	69.4 ± 3.59[a]

The mean value with different superscripts in the same column indicates the statistically significant (p<0.05).

Table. 4. Statistical analysis for plant height for all treatments with different DAT (b).

Treatment	Days After Transplanting (DAT)					
	59 DAT	66 DAT	73 DAT	80 DAT	87 DAT	94 DAT
S	83.9 ± 6.72^{ac}	95.7 ± 3.71^{ac}	101.4 ± 3.29^{ac}	106.9 ± 2.91^{ac}	107.8 ± 2.91^{ac}	109.06 ± 2.38^{ac}
Q	75.5 ± 4.78^{ab}	81.7 ± 1.27^{b}	94.2 ± 2.11^{b}	103.3 ± 1.38^{ab}	103.3 ± 1.38^{ab}	105.6 ± 0.96^{ab}
CK	84.7 ± 3.59^{a}	95.8 ± 2.11^{a}	108.6 ± 6.20^{a}	105.5 ± 0.96^{a}	105.5 ± 4.55^{a}	106.8 ± 4.47^{a}

The mean value with different superscripts in the same column indicates the statistically significant ($p<0.05$).

3.2 *Canopy Cover and Biomass Production*

The rapid development of canopy cover was observed from the tillering stage to the jointing-booting stage of rice, and the green canopy cover persisted from the heading-flowering stage until the maturity stage. The evaluation of canopy cover serves as a crucial indicator of crop growth and development. interestingly, there was no significant difference ($p>0.005$) in canopy cover among the different irrigation practices. The conventional irrigation (CK), and water-saving methods, namely shallow-deep-sallow irrigation, and shallow and frequent irrigation (Q), resulted in averaged canopy cover percentages of 64% in CK, 66% in S, and 58 in Q, respectively. These results demonstrate that water-saving irrigation practices can maintain comparable canopy cover to the conventional method, indicating similar crop vigour and photosynthetic activity. (Fig 7) shown the comparison of canopy cover between the conventional method and the water-saving method.

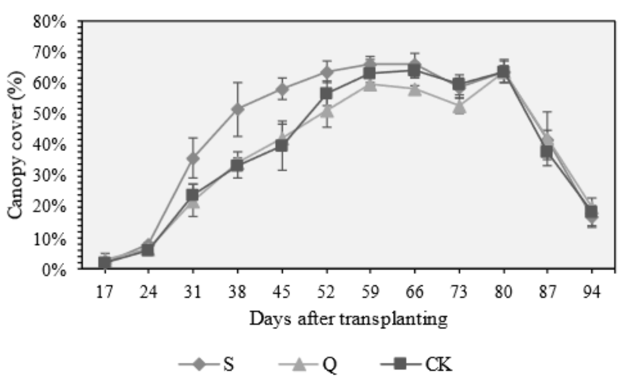

Fig 7. Canopy cover for all treatment.

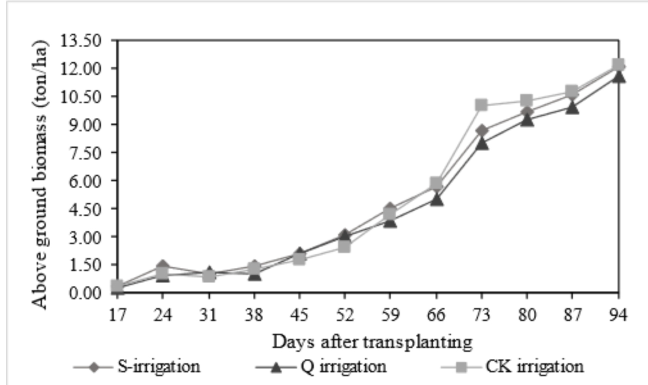

Fig 8. Above-ground biomass production in all treatments.

Rice above-ground biomass was also collected from all treatments for comparison. There was no significant difference ($p>0.05$) among treatments. Both water-saving irrigation including (S), and (Q) recorded average biomass yields of 12.1 tons/ha, and 11.5 tons/ha, respectively, while conventional treatment (CK) achieved a biomass yield of 12.2 tons/ha (Fig 8). Compared with the conventional method (CK), both water-saving methods (S), and (Q) exhibited similar canopy cover percentages and biomass production. Similar to other research by [12] reported no significant difference in canopy cover and biomass production between water-saving irrigation compared to conventional irrigation.

3.3 *Yield of Rice in Each Treatment*

There was no significant difference in rice grain yield between the water saving method and the conventional method (Fig 9). The grain yield recorded 3.2 tons/ha in the Q treatment, 3.3 in the S treatment, and 3.8 tons/ha in the CK treatment, respectively. For the 1000-gain yields ranging from 0.031 to 0.032 kg produced insignificant differences in different irrigation treatments (Fig.10). Similarly , [13] found that biomass, yield, and yield components were statically the same under the water-saving method compared continuously flooded method, and all tested levels of N, and for both the hybrid and inbred rice varieties. However, unlike other studies, the implementation of water-saving irrigation techniques led to a wide range of outcomes in terms of rice yield [14]. Some studies found that water-saving irrigation could maintain or even increase rice yield by 9% to 15% compared to traditional flood irrigation. [15,16]. In addition, [17] found that water-saving irrigation could reduce rice yield. The variability in rice yield response to water-saving irrigation is likely due to a combination of factors, including the specific irrigation method used, the rice cultivar, and the environmental conditions. The insignificant difference in our study in terms of rice yield indicates that water-saving irrigation is a good practice for rice cultivation in Cambodia.

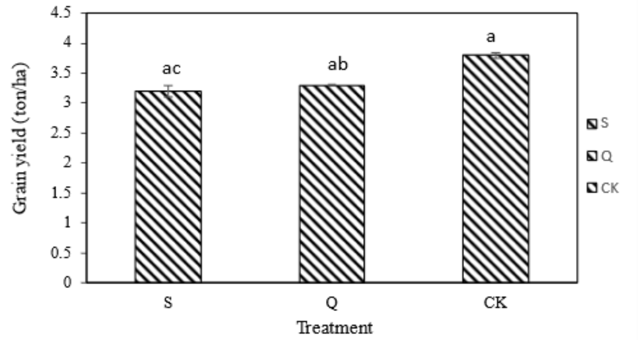

Fig 9. Rice grain yield. Graph bars with different superscript letters (a,b,c) differ significantly from each other (p<0.05).

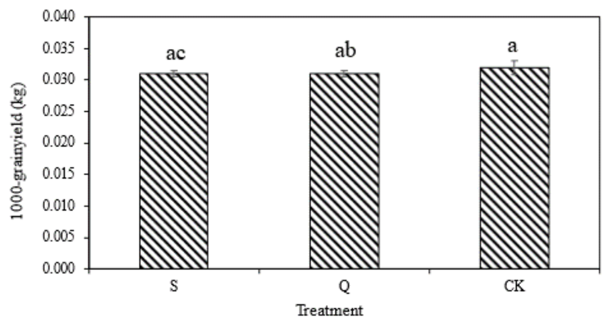

Fig.10. 1000-Grain yield of rice. Graph bars with different superscript letters (a,b,c) differ significantly from each other (p<0.05).

3.4 Water Productivity of Rice

The results showed that the total amount of water applied under the CK method was 7898 m3//ha, whereas under the S method was 5327 m3/ha, and 3660 m3/ha under the Q method (Fig 11). Water input was significantly lower under S & Q methods compared to CK method during the period of growth. The S method saved water 32.5 %, and the Q method saved 53.6 % compared to CK.

Water productivity (WP) was calculated as total grain yield per unit of total water used. WP for irrigation methods CK, S, and Q were calculated to be 0.49, 0.61, and 0.89 kg/m^3, respectively (Table.5), which indicates that water-saving irrigation management in paddy fields can improve the rice water productivity up to twice (in Q) as compared to CK method. The water productivity can be increased in S and Q treatment because total water input was remarkably reduced. The results of this study agreed with the finding by [18] found that in AWD, water productivity can be increased at the farm level due to the reduction of water input. In addition, from the previous study water productivity was higher found in water-saving compared to conventional methods, and WP ranged from 0.82 to 1.83 kg/m^3.

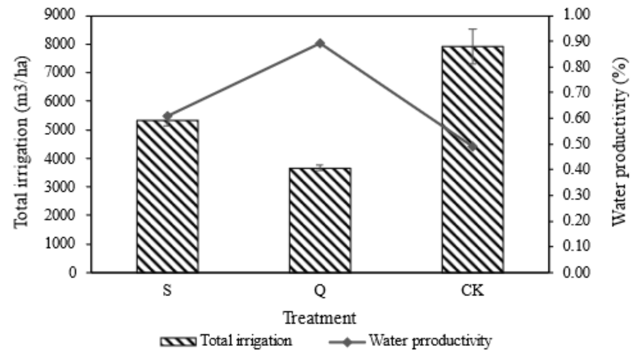

Fig 11. Total irrigation amount and Water productivity.

Table.5. Impact of water-saving irrigation on Yield and water productivity.

Treatment	Irrigation amount (m^3/ha)	Yield of rice (ton/ha)	Water productivity (kg/m3)
S	5327 ± 202.5^c	3.2 ± 0.09^{ac}	0.61 ± 0.176^c
Q	3660 ± 95.39^b	3.3 ± 0.01^{ab}	0.89 ± 0.003^b
CK	7898 ± 611.63^a	3.8 ± 0.05^a	0.49 ± 0.080^a

The mean value with different superscripts in the same column indicates the statistically significant (p<0.05).

4. CONCLUSION

In this research, two water-saving irrigation methods (S & Q) were applied to find out their effect on rice growth, rice yield, and water productivity, as well as to select the most suitable water-saving irrigation method for rice cultivation. The results of this study indicated was no significant difference in grain yield, 1000-grain yield, canopy cover, and biomass production among the treatments. However, higher water productivity and water saving were found in the treatment Q and S compared to CK. WP ranged from 0.49, 0.61, and 0.89 kg/m^3 in CK, S and Q, respectively. Therefore, it is concluded that water-saving irrigation is one of the best irrigation management practices in paddy fields during the dry season when there are water shortages by which a considerable amount of water is saved and the rice WP increases markedly. Water-saving irrigation saved water around 32.5 % and 53.6 % in treatments S and Q, respectively. The design of water-saving method combined with proper fertilization should be addressed in further research, while soil types in various areas are also considered significant factors.

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