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Original Research

Effect on Physiological Growth and Water Utilization of Rice under Different Varieties and Irrigation Modes

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Abstract

Different rice varieties and irrigation modes could affect water consumption of rice, which in turn could affect field water utilization. This study conducted experimental research on physiological indicators of rice growth and water utilization efficiency, to study their inner relationship under different rice varieties and irrigation modes. The results showed that, the effect of rice variety on water consumption was not significant ($P>0.05$), while it was obviously higher for conventional irrigation rather than that for water-saving irrigation modes. The effect of rice variety on rice height was extremely significant ($P\leq0.01$), while the irrigation method effect was not significant ($P>0.05$). Hybrid rice showed a better growth status at late growth stage of rice leaves and root activity, which was favorable for nutrient absorption and high rice production.The average yield of hybrid rice was 31.9% higher than that of conventional single-season rice.The average WUE_I and WUE_{ET} under conventional single-season rice was 20.3% and 22.7% lower than that under hybrid rice. The effect of rice variety on yield and WUE both showed significant difference ($P\leq0.05$). After principal component analysis on different rice varieties, there were 2 and 3 principal components for single-season rice and hybrid rice respectively. Path relationship on water demand-comsumption-yield showed that field leakage had a significant positive impact on irrigation amount, water consumption, water utilization efficiency, and yield, while it had a significant negative impact on evapotranspiration. Irrigation amount had a significant negative impact on water consumption and water utilization efficiency of irrigation.

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Water consumption had a significant positive impact on evapotranspiration. Water utilization efficiency of evapotranspiration had a significant positive impact on yield.

Keywords: hybrid rice, water-saving irrigation, physiological growth indicator, yield, WUE

Introduction

Rice is the main food crop in China. As the world's largest producer and consumer of rice, China's rice planting area has stabilized at an average of more than 30 million hectares, exceeding 28% of the total area of food crops [1]. The area of rice in Zhejiang province accounts for 30% of the total grain production in China. The main rice varieties in Zhejiang province are hybrid rice (like Yongyou 9, Chunyou 84, Zheyou 18, Zhongzheyou 1, Qianyou 1890, etc.) and conventional rice (like Shaojing 18, Zhejing 88, Xiushui 134, etc.) [2, 3]. There is a lot of research evidence that different rice varieties may have different growth characteristics, absorption and transformation capacity. Among them, the yield potential of hybrid rice is generally 10-20% higher than that of conventional rice, and its nitrogen absorption capacity is higher than that of conventional rice [4, 5]. Indica-Japonica hybrid rice is a hybrid rice variety of Indica and Japonica. It has tall plants, large panicles and many grains, strong tillering potential, reasonable canopy structure, obvious advantages in photosynthetic characteristics, strong lodging resistance, developed root systems, and significantly strong nitrogen absorption capacity [6, 7]. The water utilization efficiency of indica-japonica hybrid rice and japonica hybrid rice increased by 13.7%-16.8% and 5.9%-8.3% respectively under alternate wetting and soil drying compared to conventional irrigation [8]. At the same time, some researchers studied from the rice plant itself and found that rice varieties with large root surface area, long total root length, and strong root vitality have strong nitrogen absorption capacity [9]. The strong enzyme activity is closely related to the strong nitrogen absorption capacity of rice. Some researchers have combined the characteristics of rice roots with the process of soil nitrogen transformation, proving that hybrid rice varieties have developed root aeration tissues, which could promote the development and elongation of rice lateral roots, indirectly increasing nitrogen absorption efficiency.

Aiming at high rice yield and efficient utilization of water (irrigation or rain), a number of modern agricultural water-saving technology which are suitable for our country's national conditions have been developed in recent years [8, 10, 11]. Alternate wetting and soil drying [12, 13], water level controlled irrigation [14, 15], and rain-water storage irrigation [16, 17] are common water-saving irrigation techniques in recent years. Researchers have found the water utilization efficiency under conventional flooding irrigation decreased, while it could be increased due to higher photosynthetic potential, crop growth rate, net photosynthetic rate of flag leaf and root vitality under alternation of shallow and wetting irrigation [3, 18, 19]. Lei found that dry matter accumulation decreased under controlled irrigation during the tillering stage, while the leaf area index increased at later growth stage [20]. Shi have found that the leaf area index, accumulation and allocation of photosynthate under non-sufficient irrigation treatment were lower than those of conventional irrigation treatment at early crop stage, while the compensation effect under non-sufficient irrigation was obvious at late stage [21]. Previous studies have found that the effect of water stress on root activity at different growth stages of rice was different, resulting in difference on root growth and yield. The total amount of root was higher under intermittent irrigation, compared to flooding. The growth of root system was promoted under moderate drought condition, while it was restricted and root length decreased with severe drought [22, 23].

At present, the research at home and abroad mainly focuses on the high-yielding agronomic characteristics of different rice varieties, and there is a lack of relevant research on the impact of different rice varieties on water demand. Various agronomic traits and physiological performance of rice are closely related to the improvement of water utilization efficiency and yield [24]. However, the mechanism of high yield and water utilization efficiency of hybrid under water-saving technique is still not clear. The experiment in our research was carried out with different rice varieties and irrigation methods to study the water demand law and physiological growth dynamics of rice. On basis of the experimental data, to analyze the difference in water utilization efficiency of the main single-cropping rice varieties (hybrid rice and conventional rice) in Zhejiang province, and the research results are useful for formulating rice irrigation and drainage strategies, and providing theoretical support for optimizing the allocation of regional water resources in Zhejiang province.

Materials and Methods

Experimental Site

This study was carried out from 2018 to 2020 at Key Irrigation Test Station of Pinghu (latitude 30°43′N, longitude 121°10′E), Zhejiang Province of China (Fig. 1). The test station belongs to the Hangjiahu Plain area, which could represent the basic characteristics of water use and environmental characteristics in the grain production area in northern Zhejiang province. It has

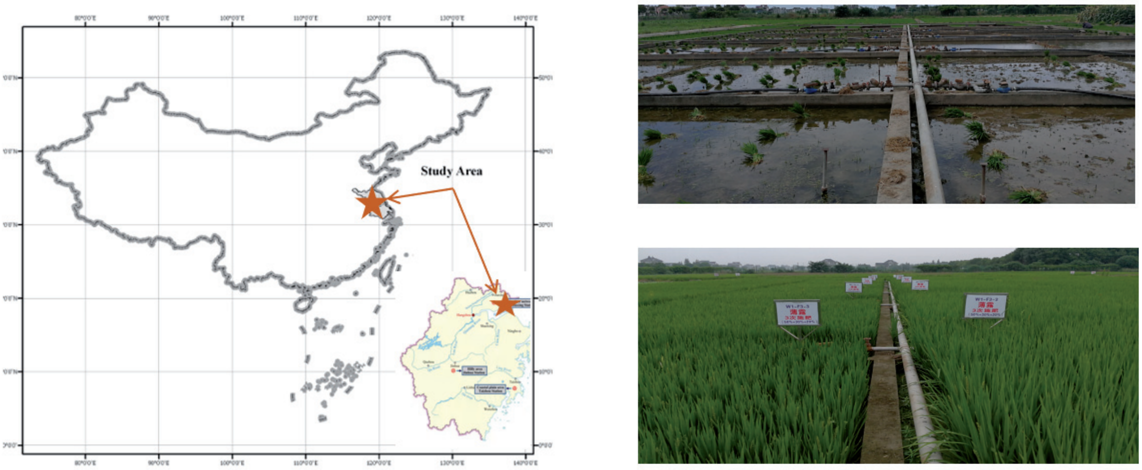

Fig. 1. Experimental site and layout.

a northern subtropical monsoon climate, with the annual average temperature about 16ºC, about 2000 sunshine hours, the annual average precipitation about 1170 mm, and the annual frost-free period about 225 days. The paddy soil of the test station is silty clay, with a bulk density of 1.3~1.4 g/cm^3. The groundwater level is relatively shallow, and it is basically maintained at 0.2~0.5 m below the field surface during the rice growth period. The test station was irrigated by pipe irrigation, and irrigation amount was measured by water meters installed in each plot. The meteorological data(daily temperature, relative air humidity, wind speed, wind direction, rainfall, sunshine, air pressure, evaporation, etc.) was monitored by automatic weather station (ZQZ-CII).

Experimental Design

The experiment mainly considered two factors: rice varieties and irrigation methods. 2 rice varieties were chosen for study, one was conventional single-season rice Xiushui 12 (X), and the other was hybrid rice Yongyou 1540 (Y). 4 irrigation methods were considered: conventional flooding irrigation (W0) referring to local customs, shallow-wetting irrigation (W1) with thin water layer, rain-dew irrigation (W2) basing on test results in recent years, and optimum rain irrigation (W3) proposed by the Water Research Institute of Zhejiang Province. The paddy water control at each growth period is shown in Table 1. Each treatment was replicated 3 times of equal size (22 m×6 m), therefore there were 24 experimental plots in total. The rice planting density was 50 plants/m^2. All experimental plots were treated with the same fertilizer management proposed by Water Research Institute of Zhejiang Province (50% basal fertilizer + 30% dressing fertilizer + 20% dressing fertilizer), with total nitrogen 225 kg/ha, P_2O_5 100 kg/ha, and K_2O 120 kg/ha, respectively.

Table 1. Controlling targets of soil moisture during paddy rice growth stage.

Treatment	Lower-upper limit	Re-greening	Tillering		Jointing-booting	Heading-flowering	Milkying
			Early	Late			
W0	Lower limit	20	20	30	30	10	10
	Upper limit	30(50)	50(70)	60(90)	60(100)	50(100)	50(60)
W1	Lower limit	5	0.8 θ_s	0.7 θ_s	0.9 θ_s	0	0.8 θ_s
	Upper limit	30(40)	20(50)	20(0)	30(60)	30(60)	20(30)
W2	Lower limit	5	0.8 θ_s	0.7 θ_s	0.9 θ_s	0	0.8 θ_s
	Upper limit	30(50)	20(80)	20(0)	30(140)	30(120)	20(80)
W3	Lower limit	0	0.8 θ_s	0.7 θ_s	0.8 θ_s	0.8 θ_s	0.8 θ_s
	Upper limit	20(50)	0(100)	0(150)	0(200)	0(300)	0(150)

Notes: (1) The first number of upper limit is the storage depth of irrigation water in mm, and the second number in parentheses is the storage depth of rainfall in mm in the paddy field. The lower limit means the field needs irrigation when the soil moisture or water storage depth of field reached this level. (2) θ_s is the field water holding capacity in %.

Indicators and Methods

Water consumption was measured by the change of water level in field surface according to the measuring needle when there has a water layer, while it was measured by soil water content change according to soil moisture analyzer at 8:00 am everyday. Water leakage was measured by the leakage meter every day, and then the leakage amount was calculated according to reading difference by the measure needle before and after. The transpiration was the difference between water consumption and leakage.

Plant height before heading stage was measured from soil surface to the highest blade tip by a measuring tape, and the height after heading stage was from soil surface to the top of the highest spike. Leaf area index (LAI) was measured by LAI-2000 canopy analyzer at 10:00 in sunny days. The canopy analyzer was placed between two rows of rice plants when measuring, and the probe was set to the north-south direction. The level of tripod and the probe should be ensured. At each growth stage, 3 rice plants were selected randomly, then the root part was separated from the above ground part and washed for measurement. After cleaning, the root length, root weight, root-shoot ratio and white-yellow black root amount were investigated. Fresh root weight was measured with an electronic scale, main root length was measured by the ruler, and ratio of white root was calculated by counting.

Dry matter accumulation in above ground part was measured by selecting 3 representative plants, and then the stems, leaves and spike were cleaned separately before being killed out in the drying cabinet at 105ºC for 1h. After that, the rice plants were dried in oven at 80°C to constant weight. At the end, the rice plant biomass of each part was weighed by a electronic scale.

WUE was defined as WUE = Y/W, where Y (kg/m^2) is rice yield; and W (m) is the total irrigation water amount or water consumption. Theoretical yield of rice was calculated by yield components. The yield components viz. productive panicle number, kernel weight and kernel number per panicle were determined by experimenter's counting. Before harvesting, plant sample was randomly selected in each pit, to count the number of panicles and the number of solid glutinous grains in the specified area, and then calculate the seed setting rate. After harvesting, 1000-grain weight and theoretical yield was calculated by randomly selecting 1000 grains of solid particles.

Data Analysis

Simple data calculation and diagramming were completed by Excel 2010. Correlation analysis and regression analysis were carried out by IBM SPSS Statistics 22. The path analysis according to SEM (structural equation modeling) was carried out by AMOS.

Results and Discussion

Water Consumption

The water consumption was the sum of evapotranspiration and leakage, and it was shown in Fig. 2. It was clear that under the same irrigation method, the water consumption, evapotranspiration and leakage for X were lower than that for Y, however the difference was not significant (P>0.05). Under the same rice variety, the leakage for W0 was obviously higher than that for water-saving irrigation modes (W1, W2 and W3). The evapotranspiration showed the trend of W0>W3>W2>W1, and the water consumption also showed W0>W3>W2>W1, which illustrated significant water saving benefits for water-saving irrigation modes. With comparisons to different water-saving irrigation methods, W1 showed the best considering water-saving effect, followed by W2, and W0 was the worst. Compared to W0, the water consumption for W1, W2, W3 was decreased by 132.4 mm, 42.9 mm, 40.2 mm, that was 27.5%, 8.9%, 8.4% reduction respectively. The evapotranspiration was decreased by 24.8%, 4.8%, 4.7% and leakage was decreased by 50.4%, 40.1%, 36.3%.

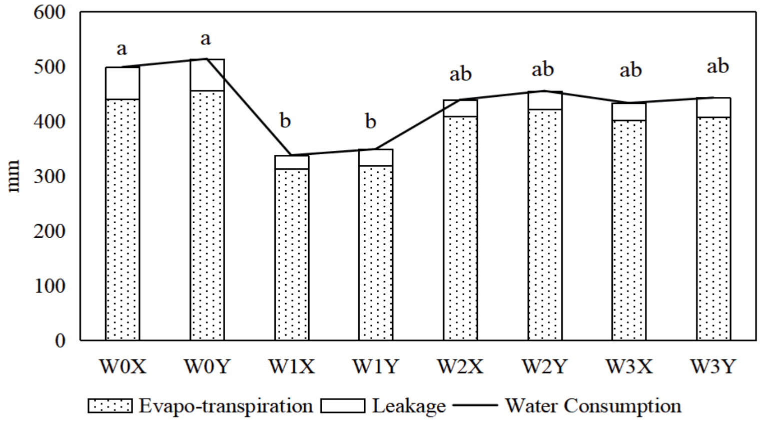

Fig. 2. Water consumption under different rice varieties and irrigation methods (2018-2020).

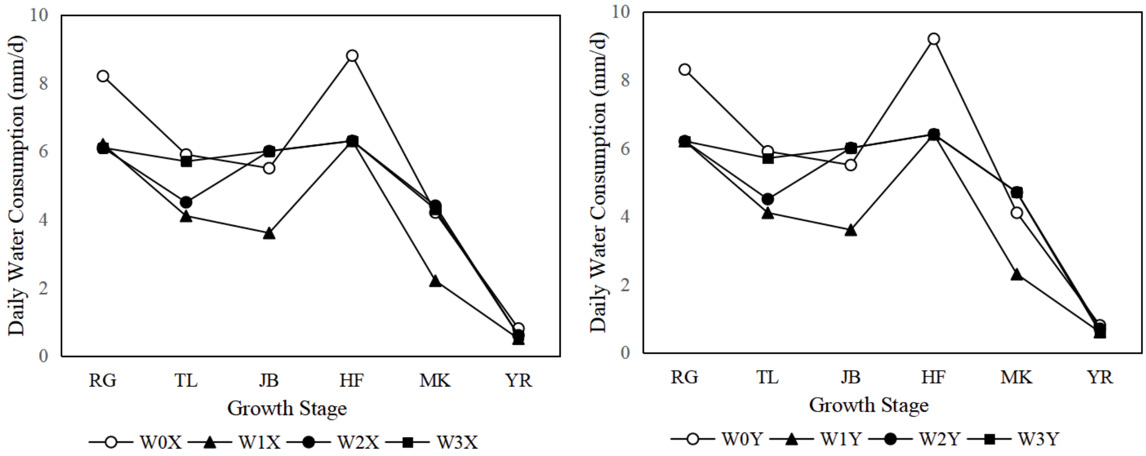

Fig. 3. Daily water consumption at each growth stage under different rice varieties and irrigation methods (2018-2020).
Note: RG, TL, JB, HF, MK, YR represent regreening, tillering, jointing-booting, heading-flowering, milkying, yellow ripeness stages of rice.

The daily water consumption under different rice varieties and irrigation modes was shown in Fig. 3. The water consumption discipline was basically the same under the same irrigation mode, and the effect of rice variety on daily water consumption was not significant. The change trend of daily water consumption for W2 and W3 was closest during whole growth stage, while W0 and W1 showed the similar change trend. The peak values of water consumption were mainly occurred at regreening stage and heading-flowering stage, with the highest at heading-flowering stage. This was mainly due to the vigorous growth of rice at this stage, and both the field evaporation and plant transpiration were at their maximum because of the relatively hot climate. As for regreening stage, the high daily water consumption was because of the long duration period. Under the same rice variety, the peak value of daily water consumption was W0>W2≈W1≈W3. Compared to W0, the daily water consumption was reduced by 25%, 25%, 26% respectively under W1, W2, W3 for X, while they were 23%, 23%, 23% respectively under W1, W2, W3 for Y.

The water requirement of rice mainly reflects the biological characteristics of plants and varieties. At the same time, it is affected by climate. The experimental results showed that the water consumption was not affected by rice varieties, but was greatly affected by irrigation modes. Because of effectively controlling the field water layer and alternating between dry and wet, the water-saving irrigation mode could significantly reduce the water demand of paddy field through reducing water surface evaporation while ensuring the physiological water demand (transpiration) of rice and the ecological water demand of the rice field. W1 and W2 both adopted the alternate dry and wet irrigation technology, and the water-saving benefit of them was significantly better than that of W3.

Change of Yield and WUE

The rice yield and water use efficiency (WUE) under different rice varieties and irrigation methods from 2018 to 2020 was shown in Table 2. The averaged

Table 2. Yield and WUE under different rice varieties and irrigation methods (2018-2020).

Treatment	Yield (kg/ha)	WU (m^3·ha)		WUE (kg·m^{-3})	
		Irrigation amount	Water consumption	WUE_I	WUE_{ET}
W0X	8411.9 a	2680.6	5504.5	3.1 a	1.5 a
W0Y	11098.5 b	2770.1	5644.8	4.0 ad	2.0 ab
W1X	8586.6 a	1643.3	3983.6	5.2 b	2.2 a
W1Y	11259.7 b	1692.5	4088.1	6.7 bd	2.8 ab
W2X	8374.6 a	600.0	4998.5	13.9 c	1.7 a
W2Y	11062.7 b	641.8	5150.7	17.2 cd	2.1 ab
W3X	8344.8 a	425.4	5074.6	19.6 c	1.6 a
W3Y	11047.8 b	528.4	5191.0	20.9 cd	2.1 ab

yield under W0, W1, W2 and W3 was 9755.2 kg/ha, 9922.4 kg/ha, 9719.4 kg/ha, and 9695.5 kg/ha. Therefore, the yield under W1 was highest among the four irrigation methods, and it was 1.7%, 2.1% and 2.3% higher than W0, W2 and W3, respectively. In comparison with different rice varieties, the yield was 31.9% higher for Y. The variance analysis showed that the effect of irrigation methods on yield was not significant (P>0.05), while the rice variety showed extremely significant effect on yield (P≤0.01).

The average irrigation water use efficiency (WUE_I) under W0 was lowest (3.6 kg/m^3), and it was 6.0 kg/m^3, 15.5 kg/m^3, 20.3 kg/m^3 under W1, W2 and W3. The average WUE_I under X (6.3 kg/m^3) was 20.3% lower than that under Y (7.9 kg/m^3), and WUE_{ET} under X (1.7 kg/m^3) was 22.7% lower with comparison to Y (2.2 kg/m^3). The conventional flooding irrigation showed extreme significance with other water-saving irrigation methods (P≤0.01), and also W1 showed extreme significance with W2 and W3 (P≤0.01). The effect of irrigation methods on water consumption use efficiency (WUE_{ET}) was not significant (P>0.05). Due to the significant difference of yield between X and Y, the effect of rice variety on WUE_I and WUE_{ET} all showed significant difference (P≤0.05) .

Change of Physiological Growth Characteristic

Rice Height and Panicle Length

The plant height under different rice varieties and irrigation methods from 2018 to 2020 was shown in Fig. 4. The average rice height after harvest under X and Y was 76.9 cm and 102.3 cm, respectively, while it was 89.8 cm, 89.8 cm, 89.3 cm and 89.8 cm under W0, W1, W2 and W3. It was obvious that the final rice height for Y was 33% higher than that for X on average, while there was little difference among different irrigation methods under the same rice variety. The variance analysis showed the effect of rice variety on height was extremely significant (P≤0.01), while the irrigation method was not significant(P>0.05). From the results above, rice height was less affected by irrigation method, and the rice variety characteristic, the plant height for hybrid rice increased greatly than conventional rice.

LAI Dynamics

The leaf area index (LAI) during the growth stage of rice under different rice varieties and irrigation methods from 2018 to 2020 was shown in Fig. 5. With comparisons to different irrigation methods, they all showed the trend of increasing from tillering to jointing-booting stage, and then it increased slowly and reached its peak at heading-flowering stage for W0 and W1, while the peak value was at milkying stage for W2 and W3. Therefore W2 and W3 showed a better growth status at late growth stage of rice, and at this stage the rice was entering to reproductive stage, while rice leaves started to recession for W0. Also, the increasing rate of W2 (8.6%) from heading-flowering stage to milkying stage was obviously higher than that of W3 (3.0%), the peak value for W2 was 1.6% higher than that for W3, indicating W2 was more favorable for growth of leaves.

Under two rice varieties, the LAI of Y was 23% higher than that of X during whole rice growth stage, and the difference between rice varieties was significantly (P≤0.01). LAI increased rapidly at the beginning from tillering to jointing-booting stage for both X and Y, and then it increased slowly to peak value for X, while it decreased slowly to a lower value for Y. Finally it gradually decreasing for X, while it increased to peak value then decreasing for Y. The peak value of Y was at milkying stage, while it was at heading-flowering stage. Therefore, it showed a better growth status for hybrid rice at late growth stage of rice leaves, which was favorable for high rice production.

Root System

The dynamics of root system during growth stage of rice under different rice varieties and irrigation methods from 2018 to 2020 was shown in Fig. 6 and Table 3.

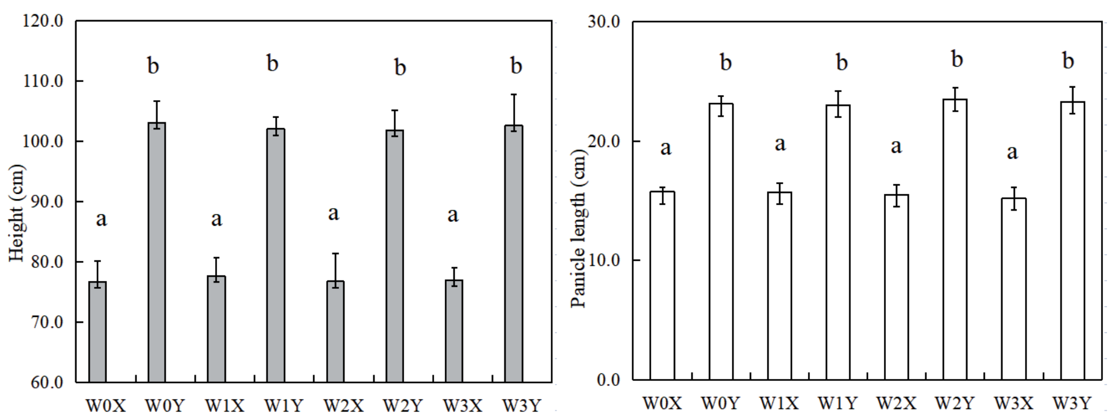

Fig. 4. Plant height and panicle length under different rice varieties and irrigation methods (2018-2020).

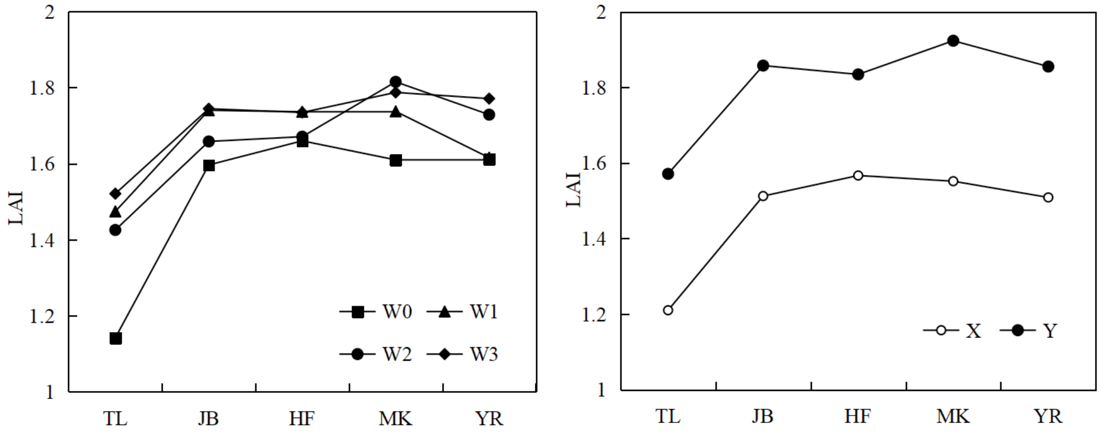

Fig. 5. LAI dynamics under different rice varieties and irrigation methods (2018-2020).
Note: TL, JB, HF, MK, YR represent tillering, jointing-booting, heading-flowering, milkying, yellow ripeness stages of rice.

Generally speaking, the root length under W3 treatment was highest during whole growth stage, and was about 50% higher than other irrigation methods, especially at tillering and jointing-booting stages, and the rest three irrigation methods had little difference and varied not much at each growth stage. It reduced gradually from tillering stage under W0 and W1, while it increased a little, and then reduced rapidly to a lower value under W2 and W3. Therefore, W3 could effectively promote root growth downwards, which was favorable for absorbing nutrients in deep soil layers. Under 2 rice varieties, the length of rice root for Y was obviously higher (14.7%) than that for X, which was mainly due to the higher transport rate and efficiency of assimilates for hybrid rice, further promoting root growth. It reached peak value at tillering stage, and decreased gradually for Y. As for X, it increased to peak value at jointing-booting stage, and then decreased gradually. The variance analysis showed the effect of rice variety on root length was extremely significant ($P \leq 0.01$), and the irrigation method was significant($P \leq 0.05$).

The root system activity could be reflected by white root ratio shown in Table 3. It could be seen that white root ratio reduced gradually with growth stage under 4 irrigation modes, illustrating the root activity decreased. Like the main root length change trend, W3 also showed the best during the whole growth stage, illustrating reasonable water stress was favorable for improving root activity. In comparison to W1 and W2, the decreasing rate under W1 was higher, showing that too much water was not favorable for containing a certain white root ratio. Rice variety could obviously affect growth and activity of root system. Therefore, W3Y could promote root growth and maintain better root activity, which was the best irrigation method for rice growth.

Dry Matter Accumulation

The dry matter accumulation (DMA) under different rice varieties and irrigation methods during rice stages from 2018 to 2020 was shown in Fig. 7. It increased

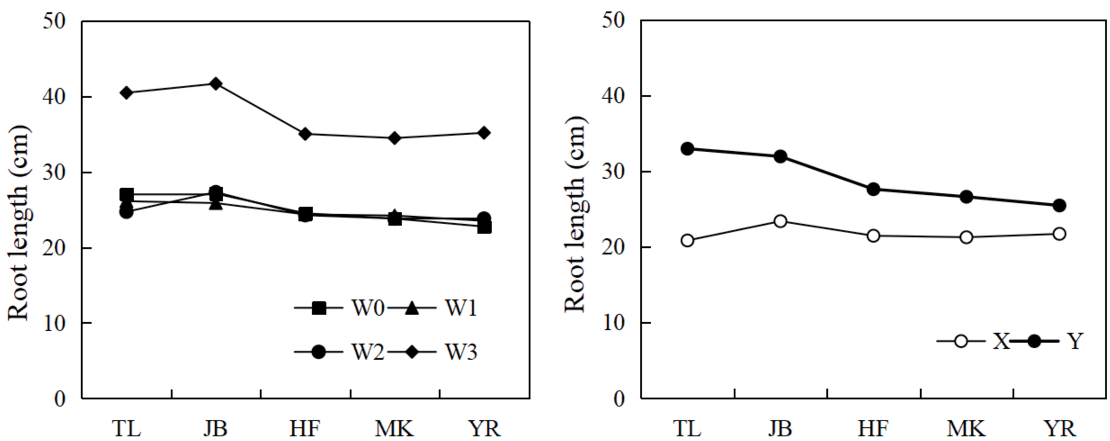

Fig. 6. Change of root length under different irrigation methods and rice variety (2018-2020).
Note: TL, JB, HF, MK, YR represent tillering, jointing-booting, heading-flowering, milkying, yellow ripeness stages of rice.

Table 3. Dynamic of root system under different treatments (2018-2020).

Treatment	Tillering		Jointing-booting		Heading-flowering		Milkying		Yellow ripeness	
	Total root amount	White root ratio	Total root amount	White root ratio	Total root amount	White root ratio	Total root amount	White root ratio	Total root amount	White root ratio
W0X	288	3.97%	268	4.85%	275	4.36%	267	4.30%	303	3.30%
W0Y	431	4.61%	441	4.54%	441	3.40%	425	3.16%	409	2.69%
W1X	308	4.41%	279	5.38%	260	5.00%	310	4.03%	263	3.42%
W1Y	431	4.36%	451	4.21%	487	3.29%	471	3.29%	427	3.04%
W2X	230	6.98%	284	5.63%	307	3.58%	273	3.41%	274	2.19%
W2Y	441	4.26%	445	4.72%	486	3.70%	437	3.31%	448	2.68%
W3X	312	5.41%	285	5.96%	283	5.30%	269	4.67%	301	2.33%
W3Y	442	4.25%	464	6.90%	472	4.03%	430	3.86%	415	3.13%

gradually with growth stage of rice, and the increasing rate was rapidly from tillering to milkying stage, while it was slow at yellow ripeness stage.

With different irrigation methods, the DMA under W0 was lowest at all growth stages, while it was highest under W3 except at tillering stage. At tillering stage, the DMA under W1 was highest, showing a better growth status for shallow-wetting irrigation. However, it was surpassed by W2 and W3 at milkying stage. Therefore, W2 and W3 showed better DMA effect at late growth stage of rice, which was consistent with results above. The DMA under W1, W2, W3 was 7.2%, 4.1%. 0.6% higher compared to W0. The irrigation method showed significant effect on DMA ($P \leq 0.05$). As for different rice varieties, the DMA showed Y>X in general. The difference between X and Y was increasing with rice growth. At tllering stage, the DMA for Y was 91.8% higher than X, illustrating a better growth status at beginning for hybrid rice. Then the increasing rate reduced to 37.3% at jointing-booting stage, and then increased to a higher level of 76.9% at heading-flowering stage, finally reduced gradually to a lower level. The rice variety effect on DMA was extremely significant ($P \leq 0.01$).

Multiple Regressions and Principal Component Analysis

Taking rice plant height (X_1), panicle length (X_2), leaf area index (X_3), root length (X_4), dry matter accumulation (X_5), rice yield (X_6), WUE of conventional single-season rice Xiushui 12 (X_7) and hybrid rice Yongyou 1540 (X_8) as variables, then principal component analysis was conducted by SPSS, and the results were shown in Table 4(a, b), Table 5(a, b) and Fig. 8. It can be seen that WUE was significant positively related to X_1 and X_6 for single-season rice, while for hybrid rice, WUE showed week positive relation to X_4 and week negative relation to X_2. There were 2 and 3 main components for single-season rice and hybrid rice respectively. For single-season rice, the first main component (Y_1) was positively correlated to X_1, X_2, X_5, X_6, X_7 ($Y_1 = 0.142X_1+0.183X_2-0.198X_3-0.157X_4-0.172X_5+0.192X_6+0.144X_7$), and negatively correlated

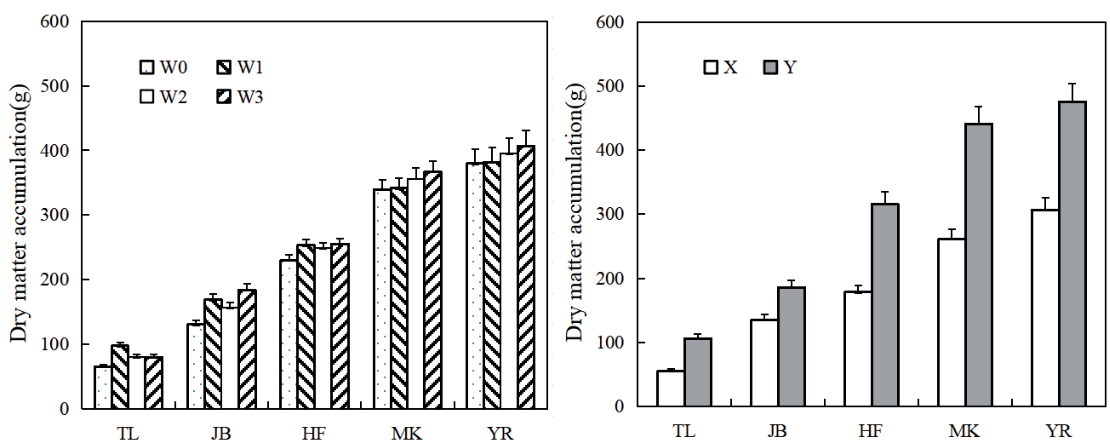

Fig. 7. Dynamics of dry matter accumulation under different rice varieties and irrigation methods (2018-2020).
Note: TL, JB, HF, MK, YR represent tillering, jointing-booting, heading-flowering, milkying, yellow ripeness stages of rice.

Table 4. a) Correlation matrix about principal component analysis for conventional rice.

	X_1	X_2	X_3	X_4	X_5	X_6	X_7
X_1	1.000	0.305	-0.501	-0.344	-0.208	0.897	0.941
X_2	0.305	1.000	-0.962	-0.741	-0.994	0.695	0.386
X_3	-0.501	-0.962	1.000	0.849	0.927	-0.821	-0.506
X_4	-0.344	-0.741	0.849	1.000	0.697	-0.590	-0.180
X_5	-0.208	-0.994	0.927	0.697	1.000	-0.619	-0.310
X_6	0.897	0.695	-0.821	-0.590	-0.619	1.000	0.896
X_7	0.941	0.386	-0.506	-0.180	-0.310	0.896	1.000

Table 4. b) Correlation matrix about principal component analysis for hybrid rice.

	X_1	X_2	X_3	X_4	X_5	X_6	X_8
X_1	1.000	-0.368	-0.271	-0.486	-0.196	-0.307	0.035
X_2	-0.368	1.000	0.813	0.387	0.765	-0.771	-0.500
X_3	-0.271	0.813	1.000	0.795	0.995	-0.671	0.083
X_4	-0.486	0.387	0.795	1.000	0.801	-0.100	0.585
X_5	-0.196	0.765	0.995	0.801	1.000	-0.675	0.145
X_6	-0.307	-0.771	-0.671	-0.100	-0.675	1.000	0.452
X_8	0.035	-0.500	0.083	0.585	0.145	0.452	1.000

Table 5. a) Component matrix about principal component analysis for conventional rice.

Component	Initial eigenvalues			Extract the sum of squares loading		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
X_1	4.885	69.792	69.792	4.885	69.792	69.792
X_2	1.688	24.112	93.903	1.688	24.112	93.903
X_3	0.427	6.097	100.000			
X_4	3.007E-016	4.295E-015	100.000			
X_5	3.032E-017	3.332E-016	100.000			
X_6	-7.813E-018	-1.116E-016	100.000			
X_7	-5.903E-016	-8.433E-015	100.000			

Table 5. b) Component matrix about principal component analysis for hybrid rice.

Component	Initial eigenvalues			Extract the sum of squares loading		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
X_1	3.855	55.072	55.072	3.855	55.072	55.072
X_2	1.984	28.344	83.416	1.984	28.344	83.416
X_3	1.161	16.584	100.000	1.161	16.584	100.000
X_4	9.031E-016	1.290E-014	100.000			
X_5	3.561E-016	5.087E-015	100.000			
X_6	-1.338E-016	-1.911E-015	100.000			
X_8	-6.813E-016	-9.733E-015	100.000			

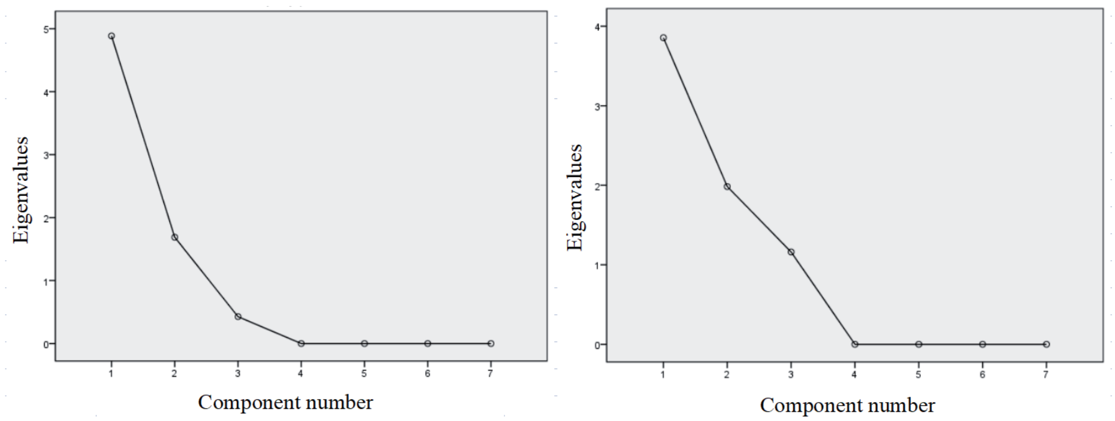

Fig. 8. Gravel figures for single-season rice and hybrid rice.

to X_3 and X_4, while the second main component (Y2) was positively correlated X_1, X_3, X_4, X_5, X_6, X_7, and negatively correlated to X_2 ($Y_2 = 0.415X_1 - 0.238X_2 + 0.147X_3 + 0.231X_4 + 0.281X_5 + 0.207X_6 + 0.409X_7$). As for hybrid rice, the first main component was positively correlated to X_2, X_3, X_4, X_5, and negatively correlated to X_1, X_6 and X_8, while the second main component was positively correlated X_3, X_4, X_5, X_6, X_8, and negatively correlated to X_1 and X_2, the third main component was positively correlated X_1, X_3, X_4, X_5, X_8, and negatively correlated to and X_2 and X_6. Therefore, the main components for conventional rice and hybrid rice were different.

Path Relationship on Water Demand-Comsumption-Yield

To clarify the mechanism of irrigation modes on water demand, water consumption, WUE and yield, structural equation model was used to analyze the relationship among irrigation amount (IRA), water consumption (WCA), leakage (LK), evaportranspiration (ET), water utilization efficiency of irrigation (WUE_I), water utilization efficiency of evaportranspiration (WUE_{ET}) and yield. The path analysis results was shown in Fig. 9 and the fitting results of the model parameters of were shown in Table 6. It was clear that the

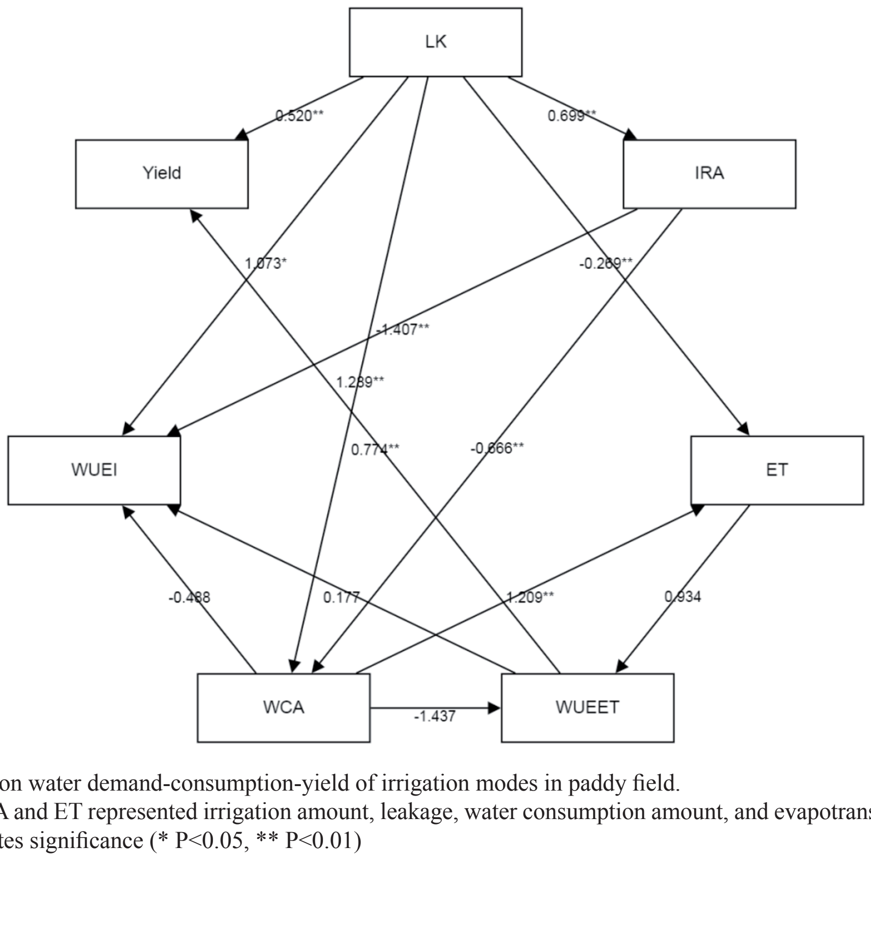

Fig. 9. Path analysis on water demand-consumption-yield of irrigation modes in paddy field.
Note: IRA, LK, WCA and ET represented irrigation amount, leakage, water consumption amount, and evapotranspiration in paddy field, and the * sign indicates significance (* P<0.05, ** P<0.01)

Table 6. Fitting indexes of structural model.

Index	χ^2	*df*	*p*	χ^2/df	GFI	CFI	NFI	NNFI
Standard	-	-	>0.05	<3	>0.9	>0.9	>0.9	>0.9
Value	15.015	8	0.059	1.877	1.000	0.977	0.953	0.939

Table 7. Effect analysis of mediation role.

X=>M=>Y	c	a	b	a*b	95% BootCI	c'	Test result	Effect size
LK=>IRA=>WUE_I	-0.215*	4.658**	-0.081**	-0.380	-1.027 ~ -0.341	0.165	Full mediation	100%
IRA=>LK=>WCA	0.166	0.104**	0.987**	0.102	0.053 ~ 0.242	0.016	Full mediation	100%
WCA=>WUE_{ET}=>Yield	0.084	-0.004*	187.598**	-0.782	-0.962 ~ -0.152	5.839	Full mediatio	100%
LK=>WUE_I=>IRA	5.555**	-0.251*	-4.866**	1.220	0.064 ~ 0.330	6.634**	Partial mediation	21.9%
LK=>ET=>WCA	3.726**	2.695**	0.986**	2.657	0.298 ~ 0.682	0.987**	Partial mediation	71.3%
LK=>IRA=>WCA	4.079**	4.658**	-0.496**	-2.310	-0.754 ~ -0.201	6.389**	Suppression effect	36.1%

Note: c represents the regression coefficient of X versus Y (when there is no intermediary variable m in the model), i.e. the total effect; a represents the regression coefficient of X versus M, b represents the regression coefficient of M versus Y, and a*b is the product of a and b, that is, the intermediary effect; 95% BootCI represents the 95% confidence interval calculated by Bootstrap sampling. c' represents the regression coefficient of X versus Y (when there is an intermediary variable M in the model), that is, the direct effect; and the * sign indicates significance (* $P<0.05$, ** $P<0.01$)

parameters (p, χ^2/df, GFI, etc.) were within the standard range, indicating that the model can be well adapted to the sample data. It illustrated that LK had a significant positive impact on IRA, WCA, WUE_I, and Yield, while it had a significant negative impact on ET. IRA had a significant negative impact on WCA and WUEI. WCA had a significant positive impact on ET. WUE_{ET} had a significant positive impact on Yield.

The analysis of the mediation effect was shown in Table 7. It can be seen that LK=>IRA=>WUE_I, IRA=>LK=>WCA, WCA=>WUE_{ET}=>Yield presented the complete mediation effects. Taking LK=>IRA=>WUE_I for example, LK's influence mechanism on WUE_I was firstly according to LK affecting the mediation variable IRA, and then affecting WUE_I. LK=>WUE_I=>IRA presented a partial mediating effect, that was, LK's influence mechanism on IRA, one part directly affecting IRA through LK, and another part through the mediating variable WUEI, the effect size was 21.9%. LK=>ET=>WCA presented a partial mediating effect, that was, the influence mechanism of LK on WCA, part of which directly influencing WCA through LK, and part of which was influenced by the intermediary variable ET, the effect size was 71.3%. LK=>IRA=>WCA presented a suppression effect, which will increase the total effect between the dependent variables and the independent variables, that was, after controlling the variable IRA, the effect of LK on WCA will be strengthened.

Conclusions

On basis of the results under different irrigation modes and rice varieties obtained above, we can draw the following conclusions.

(1) Under the same irrigation mode, the water leakage, transpiration, consumption of rice for conventional single-season rice was slightly lower than that for hybrid rice, however, the difference was not significant between different varieties ($P>0.05$), and the water-saving irrigation modes showed significantly water-saving benefits.

(2) The final rice height for hybrid rice was 33% higher than that for conventional rice. The water-saving irrigation mode and hybrid rice was conducive to the reasonable distribution and development of the leaf area of rice. The irrigation mode and rice varieties both have significant effects on the total dry matter accumulation, and dry matter accumulation under water-saving irrigation mode can increase by 9.8%.

(3) The rice yield under W1 was highest among the four irrigation methods, and it was 1.7%, 2.1% and 2.3% higher than W0, W2 and W3, respectively. In comparison to different rice varieties, the averaged yield under hybrid rice was 31.9% higher than conventional single-season rice. The variance analysis showed that the effect of irrigation methods on yield was not significant ($P>0.05$), while the rice variety showed extremely significant effect on yield ($P\leq0.01$).

(4) The average WUE_I under X was 20.3% lower than that under Y, and WUE_{ET} under X was 22.7% lower with comparison to Y. The conventional flooding irrigation showed extremely significance with other water-saving irrigation methods ($P \leq 0.01$), and also W1 showed extremely significance with W2 and W3 ($P \leq 0.01$). The effect of irrigation methods on water consumption use efficiency (WUE_{ET}) was not significant ($P>0.05$). Due to the significant difference of yield between X and Y, the effect of rice variety on WUE_I and WUE_{ET} all showed significant difference($P \leq 0.05$) .

(5) WUE was significant positively related to plant height and yield for single-season rice, while for hybrid rice, WUE showed week positive relation to root length and week negative relation to panicle length. There were 2 and 3 main components for single-season rice and hybrid rice respectively. LK had a significant positive impact on IRA, WCA, WUEI, and Yield, while it had a significant negative impact on ET. IRA had a significant negative impact on WCA and WUEI. WCA had a significant positive impact on ET. WUEET had a significant positive impact on Yield.

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Conflict of Interest

The authors declare no conflict of interest.

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