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Proceeding Paper

Effect of Different Water Stress on Growth Index and Yield of Semi-Late Rice [†]

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Abstract: The aim of this research is to find out the effects of different degrees of drought stress on the growth index and yield of semi-late rice. In this experiment, a pot experiment was conducted with hybrid Tian-you-hua-zhan rice as material. Intermittent irrigation was used as control (CK) at the tillering stage, booting stage, heading stage, and milk stage. Three water stress gradients of light drought (70% saturated moisture content), medium drought (60% saturated moisture content), and severe drought (50% saturated moisture content) were set to monitor the soil moisture content. The plant height, number of tillers, leaf area, and chlorophyll content under different water gradients at different growth stages were measured, and the effects of different water stress treatments at different growth stages on rice growth index, yield, and its components were analyzed. The results showed that the inhibition of the plant height at the jointing and booting stages was the most significant; moreover, the number of tillers and leaf area decreased most significantly at the tillering stage, and the heading and flowering stages had the greatest effect on chlorophyll synthesis. As far as yield is concerned, the most sensitive stages are the heading and flowering stages. Different stress treatments reduced the effective panicle number, 1000-grain weight, and seed setting rate of rice, and reduced the yield by 27.57%, 44.23%, and 46.32% respectively, compared with the normal control. The correlation analysis showed that the correlation degree of affecting yield from large to small was 1000-grain weight, seed setting rate, and effective panicle. Therefore, ensuring water supply at the heading and flowering stage can effectively improve the 1000-grain weight, effective panicle, and seed setting rate, and increase the rice yield and water use efficiency.

Keywords: water stress; growth index; 1000-grain weight; yield

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1. Introduction

There is a great shortage of water resources in China, and the biological characteristics of rice have great water-saving potential [1]. Therefore, in the process of rice planting, it is of great significance to study the tolerance of water stress at different growth stages and its effects on the physiological index and yield of rice [2–5]. Differences in the effects of water stress and the degree of water stress on rice growth and yield at different growth stages have been reported; compared with rice under severe water shortage, rice recovered better and had a higher compensation effect under mild water stress. Water stress at the booting stage decreases the number of effective panicles, grains per panicle, and seed setting rate, resulting in a decrease in yield [6,7]. Water stress at the flowering stage results in a significant decrease in 1000-grain weight and seed setting rate, resulting in a decrease in yield per plant [8,9]. There have been many studies on the effects of water stress on rice yield, but the conclusions are different due to different planting sites, rice varieties, and experimental methods. There are relatively few studies on the effects of water stress on rice yield and growth index in a reproductive growth stage. In this experiment, according to the actual situation of seasonal drought of rice mid-season in Jiangxi, the effects of water stress on rice yield and growth index were studied, providing theoretical support for the study of rice water requirement and water-saving irrigation in Jiangxi.

2. Materials and Methods

2.1. Experimental Design

The experiment was carried out in the irrigation experiment center of Jiangxi Province, using pot experiment, pot length 38 cm, pot width 26 cm, carried out in a mobile rain shelter to avoid the effect of rainfall on the pot culture. The middle rice variety Yangliangyou was selected, and four middle rice varieties were selected at tillering stage (T1), jointing and booting stage (T2), heading and flowering stage (T3) and milk stage (T4). The degree of drought was controlled by the soil water content after the water layer was dried, and three levels were set, which were 50% of the saturated moisture content (W1, severe drought), 60% (W2, moderate drought) and 70% (W3, light drought) respectively. The two factors were combined into 12 treatments, and another reference treatment (CK) was set up. There were 13 treatments for late rice. The reference treatment (CK) intermittent irrigation always maintains a 2–3 cm thin water layer in the green period, for 7–10 days in the late tillering period, and naturally dries in the yellow mature stage; the rest of the growth period irrigates 2–3 cm each time and dries naturally for 3–5 days, that is, the soil moisture content reaches more than 70% of the saturated moisture content, and then irrigates again and again. Each process sets three repeats, with a total of 39 cells (see Table 1).

Table 1. Experimental design of semi-late rice subjected to drought.

Serial Number	Treatment Mode	Water Condition of Paddy Field at Different Stages					
		Rejuvention Stage	Tillering Stage	Booting Stage	Heading Stage	Milk Stage	Yellow Ripening Stage
1	CK	Normal	Normal	Normal	Normal	Normal	Dorp dry
2	W1T1	Normal	70%	Normal	Normal	Normal	Dorp dry
3	W2T1	Normal	60%	Normal	Normal	Normal	Dorp dry
4	W3T1	Normal	50%	Normal	Normal	Normal	Dorp dry
5	W1T2	Normal	Normal	70%	Normal	Normal	Dorp dry
6	W2T2	Normal	Normal	60%	Normal	Normal	Dorp dry
7	W3T2	Normal	Normal	50%	Normal	Normal	Dorp dry
8	W1T3	Normal	Normal	Normal	70%	Normal	Dorp dry
9	W2T3	Normal	Normal	Normal	60%	Normal	Dorp dry
10	W3T3	Normal	Normal	Normal	50%	Normal	Dorp dry
11	W1T4	Normal	Normal	Normal	Normal	70%	Dorp dry
12	W2T4	Normal	Normal	Normal	Normal	60%	Dorp dry
13	W3T4	Normal	Normal	Normal	Normal	50%	Dorp dry

2.2. Observation Items and Methods

The control methods of the soil moisture are as follows: (1) before rice planting, weigh the test chamber, measure the quality of wet soil and test box, measure the soil moisture content by drying method, and then calculate the dry soil mass in each soil box; (2) in the process of drought test after rice planting, weigh the weight in the test box, calculate the soil water content in the test box, and control the soil water content.

Plant height: measure the distance from the surface of the potted soil layer to the top of the longest leaf before the heading and flowering stages, and the distance from the surface of the potted soil layer to the longest ear from the heading stage to the later stage.

Number of tillers: from the tillering stage, the number of tillers per pot was recorded and measured every five days.

Chlorophyll: using a hand-held SPAD-502 chlorophyll tester, six plants were selected for each plant, one leaf was completely opened for each plant, the SPAD values at the middle part of the leaf and at the upper and lower parts of the leaf were measured, and the average SPAD values were taken.

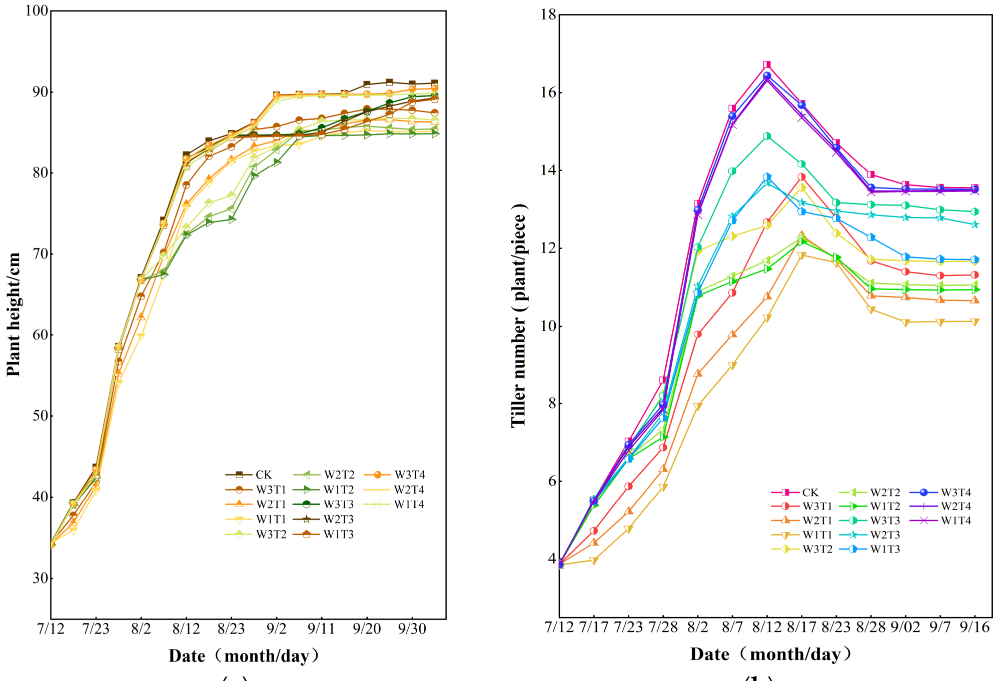
Leaf area: the first three plants of each pot were measured directly with a ruler, three inverted sword leaves were measured in each plant, and the midvein length and maximum leaf width of each leaf were measured, respectively.

Yield and quality: according to the results of the effective panicle investigation, three plants were selected in each pot area for seed testing; at the same time, the yield of all rice plants in each pot was measured. The content of seeds examination include the effective panicle length, effective panicle number, total grains per panicle, filled grain weight per panicle, 1000-grain weight, and actual yield.

3. Results

3.1. Analysis of Growth Indexes of Rice under Different Water Stress

It can be seen from Figure 1a that drought stress has an inhibitory effect on the plant height of rice during the whole growth stage, and the order of the plant height from high to low under each water stress is as follows: CK > W3T4 > W2T4 > W1T4 > W3T3 > W2T3 > W1T3 > W3T2 > W2T1 > W2T2 > W1T1 > W1T2. It can be seen from the figure that drought stress has the most significant inhibitory effect on the plant height at jointing and booting stages, and the effect of drought stress on the plant height under drought stress is less than that in the previous two stages, which proves that water has a greater effect on the plant height growth at the vegetative growth stage.

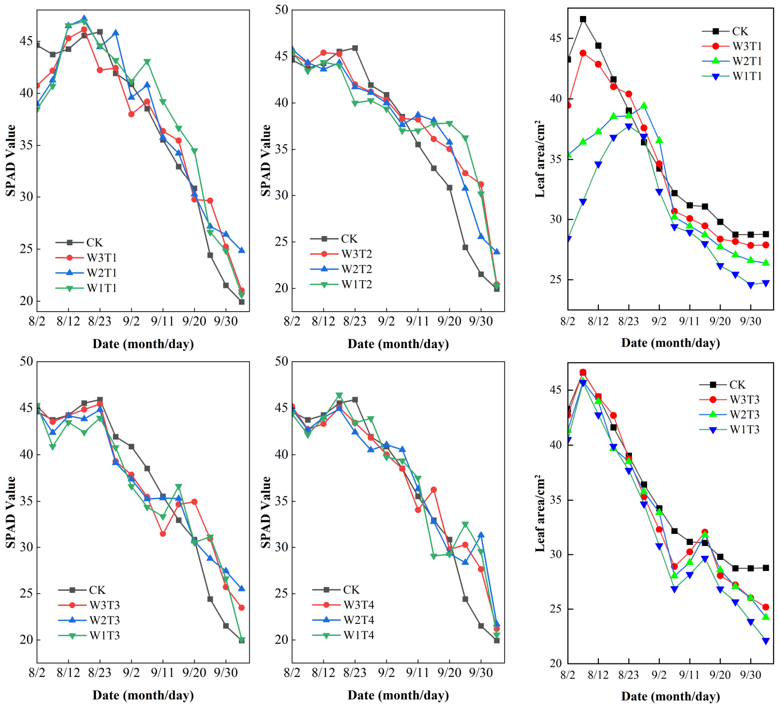


(**a**) (**b**)

Figure 1. (**a**) Rice plant height under different water stress; (**b**) Rice tillering under different drought treatments.

It can be seen from Figure 1b that water stress inhibited the tillering of rice, which decreased most obviously at the tillering stage (T1) and the booting stage (T2), followed by the heading stage (T3), and the milk stage (T4). It was proved that drought stress had a strong inhibitory effect on rice tillering at the vegetative growth stage.

It can be seen from Figure 2a that the SPAD value of rice during the overall growth period is in a downward trend, the chlorophyll content of rice will increase briefly during the same growth period, and some treatments are higher than the normal control. The treatment at stage T1 is as follows: W2 > W1 > W3 at T2 and W3 > W2 > W1 at T3, but it is basically lower than that in the normal control. During the period of T4, W3 > W2 > W1 and W3 increased briefly during drought and was higher than that of the normal control. The gradient change of the W2 treatment was smaller than that of other treatments, and the decrease of the W1 treatment was the most obvious.



(**a**) (**b**)

Figure 2. (**a**) Rice SPAD under different drought treatments; (**b**) Leaf area of rice under different drought treatments.

It can be seen from Figure 2b that water stress can inhibit the growth of the rice leaf area, in which the tillering stage and jointing stage are the most obvious, followed by the heading stage. Moreover, the effect on milky rice is less, the overall performance is W3 > W2 > W1, that is, the more serious the water deficit, the smaller the leaf area.

3.2. Analysis of Yield and Its Components under Drought Treatment

It can be seen from Table 2 that the effect of drought stress on the rice yield is the greatest at the heading stage, and the highest reduction in rice yield is 46.32%. In the same period, it is W3 < W2 < W1, and the effect at the tillering stage is the least significant.

Table 2. Examination results of yield indexes in growth period of each treatment.

Treatment	Number of Effective Ears (Piece/Pot)	1000-Grain Weight (g)	Spike Length (cm)	Number of Real Grains	Number of Real Grains	Total Grains	Seed Setting Rate (%)	Actual Yield (g/Pot)	Increase or Decrease Compared with CK (%)
CK	62	19.86	19.54	3916	245	4161	94%	77.54	0
W3T1	61	19.7	19.3	3869	341	4210	92%	76.22	−1.7
W2T1	56	19.31	18.9	3795	368	4163	91%	73.28	−5.49
W1T1	52	18.81	17.7	3640	402	4042	90%	68.47	−11.7
W3T2	58	19.2	19.3	3649	450	4099	89%	70.06	−9.64
W2T2	54	18.1	18.6	3377	484	3861	87%	61.12	−21.17
W1T2	49	17.4	18.4	3027	610	3637	83%	56.15	−27.58
W3T3	57	17.7	16.9	3173	733	3906	81%	56.16	−27.57
W2T3	53	16.3	16.8	2453	979	3432	71%	43.24	−44.23
W1T3	47	16.1	16.7	2385	1076	3461	69%	41.62	−46.32

Table 2. *Cont.*

Treatment	Number of Effective Ears (Piece/Pot)	1000-Grain Weight (g)	Spike Length (cm)	Number of Real Grains	Number of Real Grains	Total Grains	Seed Setting Rate (%)	Actual Yield (g/Pot)	Increase or Decrease Compared with CK (%)
W3T4	57	18.58	18.51	2354	610	2964	79%	58.6	−24.42
W2T4	54	17.87	18.27	2337	795	3132	75%	54.27	−30.01
W1T4	49	16.96	17.84	2264	866	3130	72%	50.27	−35.17

The yield components include 1000-grain weight, grain number per spike, seed setting rate, and effective panicle number. From the point of view of the effective panicle, in the same growth period, the order is CK > W3 > W2 > W1. In terms of seed setting rate, severe drought stress at the heading stage had the greatest effect on the rice seed setting rate, which was 25% lower than that of CK. In the same growth period, it was CK > W3 > W2 > W1. In terms of effective panicle length, severe drought stress at the heading stage had the most significant effect on the effective panicle length, with an average decrease of 2.84 cm per plant, and the order was CK > W3 > W2 > W1 in the same period. In terms of grain number per ear, light drought stress at the milk stage had the greatest effect on the grain number per ear, which was 28.77% less than that of CK. In the same growth period, the milk stage was CK > W2 > W1 > W3. In terms of 1000-grain weight, the effect of severe drought at the heading stage on the 1000-grain weight was the most obvious, which was 18.93% lower than that of CK, and the order was CK > W3 > W2 > W1 in the same period.

3.3. Correlation Analysis between Growth Indexes and Stage Water Consumption of Rice

The following conclusions can be drawn from Table 3: Under the normal irrigation level, the correlation between water consumption and plant height at the jointing stage is the largest. The correlation between water consumption at heavy drought levels and plant height at the tillering stage is the strongest, 0.947. The weak correlation between light drought and moderate drought levels at different growth stages shows that severe drought at the tillering stage will significantly impact the rice plant height. Under the conventional irrigation mode, most of the water consumption at the jointing stage is used to increase the height of the rice plant. The water consumption at light drought level is negatively correlated with the rice tillering at all stages, with the strongest correlation at the jointing stage being 0.587. The water consumption at heavy drought levels strongly correlates with the rice tillering at all stages, with the most significant correlation at the tillering stage being 0.926. Normal irrigation and moderate drought levels are weakly correlated with other treatments, indicating that under light drought level, most of the water consumed by the rice at the jointing stage was not used for the increase of tiller number, while under the heavy drought level, most of the water consumed at each growth stage was used for the increase of tiller number of rice, especially for the rice at the tillering stage, which had a significant positive correlation.

The following conclusions can be drawn from Table 4: The water consumption of rice under moderate and severe drought levels has a significant positive correlation with SPAD at the tillering, jointing, and milking stages, which are 0.919, 0.569, and 0.835, respectively. In contrast, the water consumption under normal irrigation and light drought levels have no significant impact on the SPAD value, proving that under severe stress at the tillering stage, most water consumption is used to synthesize chlorophyll. The water consumption is the main factor affecting the SPAD value change under moderate stress at the jointing stage and heading stage. Under normal irrigation, the water consumption and the leaf area at the milky stage are negatively correlated, with a coefficient of 0.765. Therefore, the water consumption does not promote the leaf area growth at the milky stage. In contrast, the water consumption and the leaf area at the jointing stage are positively correlated, with a coefficient of 0.59, indicating that the water consumption promotes the leaf area growth. Under moderate and severe drought levels, the rice leaf area and water consumption are positively correlated, with coefficients of 0.718 and 0.719, respectively. It was proved that water stress had a significant impact on the leaf area.

Table 3. Correlation analysis of water consumption with plant height and tiller number.

Index	Child-Bearing Period							
	Plant Height/cm				Tiller Number/Tiller			
Water Gradient	T1	T2	T3	T4	T1	T2	T3	T4
CK	−0.217	0.805 **	0.653 *	0.531	−0.023	0.415	0.435	0.400
W3	−0.379	−0.332	−0.523	−0.520	−0.467	−0.587 *	−0.524	−0.576 *
W2	−0.363	−0.242	0.232	0.336	−0.209	−0.014	−0.152	−0.112
W1	0.947 **	0.292	0.291	0.386	0.926 **	0.637 *	0.701 **	0.689 **

T1 represents the tillering stage of rice, T2 represents the booting stage of rice, T3 represents the heading stage of rice, T4 represents the milky stage of rice. At 0.01 level (double tail), the correlation was significant (**). At 0.05 level (double tail), the correlation was significant (*).

Table 4. Correlation analysis of water consumption with SPAD and leaf area.

Index	Child-Bearing Period							
	SPAD Value				Leaf Area/cm^2			
Water Gradient	T1	T2	T3	T4	T1	T2	T3	T4
CK	−0.418	0.548	0.190	−0.765 **	0.416	0.590 *	0.321	−0.765 **
W3	−0.389	0.427	−0.063	0.425	−0.384	0.043	0.493	0.425
W2	−0.476	0.569 *	0.835 **	0.107	−0.229	0.719 **	0.027	0.107
W1	0.919 **	−0.286	−0.627 *	−0.198	0.718 **	−0.317	0.534	−0.198

At 0.01 level (double tail), the correlation was significant (**). At 0.05 level (double tail), the correlation was significant (*).

3.4. Correlation Analysis of Water Consumption and Yield at Each Growth Stage

Table 5 shows rice's water consumption and actual yield at different growth stages under different water stress levels. Pearson correlation analysis was used to calculate the correlation coefficient between water consumption and rice yield at each growth stage. The calculation results are shown in Appendix A Table A2.

Table 5. Water consumption and actual yield at each growth stage.

Variable Treatment Mode	Water Consumption/mm				Yield/(g/Pot)
	Tillering Stage	Booting Stage	Heading Stage	Milk Stage	
CK	275.86	367.35	121.86	140.37	77.54
W1T1	274.07	366.35	120.44	117.51	76.22
W2T1	262.54	355.00	116.28	110.54	73.28
W3T1	257.15	351.78	115.40	103.32	68.47
W1T2	233.92	350.88	111.68	138.84	70.06
W2T2	212.11	311.93	101.54	131.57	61.12
W3T2	204.14	312.45	97.73	127.59	56.15
W1T3	261.87	331.18	83.70	135.93	56.16
W2T3	259.09	323.00	66.24	137.25	43.24
W3T3	248.60	299.33	58.27	132.61	41.62
W1T4	254.49	243.80	107.36	129.50	58.60
W2T4	262.01	198.53	107.84	134.21	54.27
W3T4	252.82	177.78	101.58	129.50	50.27

From the results of Pearson correlation analysis in Appendix A Table A2, the following conclusions can be drawn: The water consumption at the booting stage and heading stage is significantly correlated with the yield of rice, that is, the water deficit at the booting stage and heading stage will have a severe impact on the yield of rice, among which the correlation at the heading stage is the strongest, which is 0.88. Therefore, it is inappropriate to lack water excessively at this growth stage. In contrast, the water consumption at the tillering and milky stages are weakly correlated and negatively correlated, respectively, indicating that appropriate water stress at the tillering stage has little effect on the final yield of rice. The same is accurate at the milky stage.

4. Discussion

4.1. Effect of Water Stress on the Growth of Semi-late Rice

In this study, it was found that with different water gradients, the overall plant height of rice under heavy drought was lower than that under light and moderate drought, and, under the same water condition, the plant height was CK > T4 > T3 > T1 > T2. It can be inferred that water stress has a greater inhibitory effect on the rice plant height at the jointing stage and tillering stage, which is consistent with the research results of some scholars [10,11].

Tillering shows that under the same water stress, T1 < T2 < T3 < T4 < CK. This is because, when rice is at the reproductive growth stage, mild and moderate water stress have little effect on rice tillering at the reproductive growth stage, and it is beneficial to reduce ineffective tiller. Severe water stress leads to damage of the late filling and dry matter distribution, resulting in the death of the effective tiller, which is similar to the conclusion of Yang X L [12].

The overall photosynthesis showed a downward trend, as the SPAD value of rice at the booting stage increased during the short-term drought period, and most of the rice was higher than CK. Short-term water deficit could promote the photosynthetic potential of chlorophyll. When the drought time is longer than 10 days, the SPAD value of rice decreases continuously, which is basically consistent with the results of previous studies. This is because, at the early stage of the reproductive growth, water can affect the synthesis of chlorophyll in rice, and proper water stress can increase the concentration of chlorophyll, thus promoting the photosynthetic effect of rice.

Water stress can inhibit the growth of the rice leaves, thus inhibit the growth of the leaf area, and the overall performance is W3 > W2 > W1, that is, the more serious the water deficit, the smaller the leaf area.

4.2. Effect of Water Stress on Yield of Semi-Late Rice

In this study, from the yield and its composition, it was found that under different water treatments, the effective panicles were T1 > T2 > T4 > T3. Drought stress inhibited the differentiation of effective panicles, resulting in a significant decrease in the number of effective panicles [13,14]. It was found that the number of effective panicles of rice was very low under the irrigation mode of severe water deficit, which was similar to the results of this experiment [15]. Proper water addition was needed to improve the differentiation of effective panicles at the middle and later stages of reproductive growth.

Under the same water treatment, the panicle length of light drought was T1 $\geq$ T2 > T4 > T3, the moderate drought was T1 > T2 > T4 > T3, and the severe drought was T2 > T4 > T1 > T3. At the late growth stage, the inhibitory effect of water stress on the rice panicle length was very obvious. This is because the rice flag leaf is the main organ for the photosynthesis, therefore water deficiency will lead to the curl of the rice flag leaves and affect the opening and closing of the stomata and the synthesis of chlorophyll, so that the ear cannot grow normally [16,17].

The effect of light drought on the number of grains per panicle was the least at the tillering stage and the greatest at the milking stage. Water played a key role in the millet filling at the later stage of rice reproductive growth, and the water deficit inhibited the grain filling and starch accumulation in rice. Studies have shown that water stress significantly reduces the total amount of dry matter and limits the quantity and rate of stem and sheath carbohydrate transport to grains at the heading and flowering stages. At the same time, it accelerated the senescence of the rice leaves, led to insufficient grain filling time, and reduced the yield [18].

Under the same water treatment, the 1000-grain weight was T1 > T2 > T4 > T3, which proved that water stress had more significant inhibitory effect on the rice grain filling at the heading stage. Some scholars found that drought stress at the heading stage led to a significant decrease in the rice yield. The main factor leading to yield reduction is the decrease of the seed setting rate and 1000-grain weight due to insufficient water supply under drought stress [12], which is similar to the results of this experiment.

5. Conclusions

Based on the above analysis, the effects of different water stress on the rice growth index and yield were as follows:

(1) Water stress at different growth stages had different effects on rice growth indexes. The plant height was most significantly inhibited at the jointing and booting stages, and its water consumption was significantly positively correlated with the plant height, which was 0.805. The tillering stage most obviously affected the tiller number and leaf area. The correlation between water consumption, tiller number, and leaf area under heavy drought levels was very significant, which was 0.926 and 0.718. The heading and flowering stages had the most significant impact on chlorophyll. The correlation between water consumption and chlorophyll under medium drought levels was significant, which was 0.835.

(2) Different stress treatments reduced the adequate panicle number, 1000-grain weight, and seed-setting rate of rice. The most sensitive periods were the heading and flowering stages. Compared with the standard control, the yield of the three stress levels decreased by 27.57%, 44.23%, and 46.32%, respectively. The correlation analysis showed that the correlation degree of the yield was the 1000-grain weight, seed setting rate, and adequate panicle number (see Appendix A Table A1). The 1000-grain weight can have a more significant impact on the yield, which is 0.980.

(3) There was a specific relationship between water consumption and rice yield at different growth stages. The water consumption at the booting and heading stages was significantly correlated with the rice yield. The correlation between water consumption and yield at the heading stage was the strongest, which was 0.880.

Therefore, increasing water input at the tillering and jointing stages is beneficial to the tillering of rice, can effectively promote the stem and leaf growth and the panicle differentiation, and improve the plant height and leaf area of the rice. It is unsuitable for saving water excessively at the heading and flowering stages. Increasing the water supply can improve the 1000-grain weight, effective panicle, and seed setting rate of rice, and improve the rice yield and water use efficiency.

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Appendix A

Table A1. Correlation analysis of yield and its components.

Dimension	Effective Panicle Number	1000-Grain Weight	Number of Grains per Spike	Seed Setting Rate	Actual Yield
Effective panicle number	1				
1000-grain weight	0.820 **	1			
Number of grains per spike	0.517	0.643 *	1		
Seed setting rate	0.684 **	0.912 **	0.835 **	1	
Actual yield	0.762 **	0.980 **	0.755 **	0.961 **	1

At 0.01 level (double tail), the correlation was significant (**). At 0.05 level (double tail), the correlation was significant (*).

Table A2. Correlation analysis of water consumption and yield at each growth stage.

Dimension	Tillering Stage	Booting Stage	Heading Stage	Milk Stage	Actual Yield
Tillering stage	1				
Booting stage	0.078	1			
Heading stage	0.175	0.159	1		
Milk stage	−0.125	−0.236	−0.389	1	
Actual yield	0.247	0.585 *	0.880 **	−0.377	1

At 0.01 level (double tail), the correlation was significant (**). At 0.05 level (double tail), the correlation was significant (*).

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