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Effects of water deficit on yield and water use efficiency of rice in western Hubei, China

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ABSTRACT: In order to reasonably set the upper and lower limits of rice irrigation in western Hubei, a field plot experiment was carried out at the Dongfeng Canal Irrigation Experiment Station, and light (L, 90%-0-40), Moderate (M, 80%-0-40) and severe (H, 70%-0-40) three levels of water deficit, with full irrigation (CK, 100%-10-40) as the control, to study water deficit Effects of deficiency on rice yield and water use efficiency in western Hubei. The results showed that all the water deficit treatments could effectively reduce the water consumption in the deficit stage, and there was little difference with CK after rewatering; the water deficit treatments at the tillering stage, heading stage and milk maturity stage respectively significantly affected the effective panicle number of rice , grain number per panicle and seed setting rate, while the L treatment at the tillering stage significantly increased the number of grains per panicle and thousand-grain quality of rice, and the yield and water use efficiency were significantly higher than other treatments.

KEYWORDS : Water deficiency; Rice; Yield; Water use efficiency

I. INTRODUCTION

Currently, water scarcity has become a global problem, and water shortages ofvarying degrees exist in most parts of China, and have become a major constraint on agricultural development[1].Improving the effective utilization rate of irrigation water through the promotion of advanced water-saving irrigation technology is an inevitable choice for easing the contradiction between the supply and demand of water resources in China, solvingthe agricultural water crisis and maintaining the sustainable development of agriculture[2].

With global climate change, drought stress has become the most important environmental factor affecting rice production worldwide[3], Even in the western Hubei, which has a rainy season, rice yield reduction due to uneven spatial and temporal distribution of rainfall is becoming increasingly prominent[4]. At present, rice in West Hubei is still traditionally irrigated by flooding, and the amount of water lost through natural evaporation and seepage in this way accounts for about 80% of the amount of water irrigated in rice paddies, resulting in a large amount of wasted water resources[5].In order to scientifically and rationally optimize the allocation of irrigation water resources, scholars have proposed a loss-adjusting irrigation method that effectively utilizes the physiological functions of crops to save water, which utilizes the physiological characteristics of crop water demand for water-saving irrigation. Yang et al[6]. through the rice deficit-regulated irrigation experiment, it was found that the moderate water deficit treatment could significantly reduce rice water consumption, and it was also beneficial to improve rice yield and water use efficiency. Therefore, adopting a moderate water deficit during the appropriate reproductive period of rice is essential to ensure water conservation, yield stabilization, and quality improvement of rice.

In order to clarify the response mechanism of rice to water deficit at different fertility stages in West E region, so as to rationally determine the upper and lower limits of rice irrigation in this region. In this study, the team set up different degrees of water deficit treatments at different fertility stages of rice in a field plot experiment to study the effects of water deficit on the water consumption pattern, yield and water use efficiency of rice, with a view to providing a theoretical basis for promoting the water-saving production of rice in the western part of Hubei Province.

II. MATERIAL AND METHODS

II. Ⅰ EXPERIMENTAL LOCATION AND MATERIALS

The experiment was conducted at Dongfeng Canal Irrigation Experiment Station (30°70′ N, 111°68′ E) in Yichang City, which is a key station for irrigation experiment in Hubei Province, and the test area is near a large national reservoir (Quanhe Reservoir), and the whole area is a hilly area with a relatively flat topography and a subtropical monsoon climate, with an average annual temperature of 16.4°C, an average annual rainfall of 1,215 mm, a long frost-free period of 268 days (annual average) The average annual temperature is 16.4℃, the average rainfall is 1215 mm, and the frost-free period is 268 days (annual average), with an average of 1850 hours of sunshine, and the sunshine percentage is 41.8%. The soil in the experimental area is yellow-brown loam, with an organic matter content of 15.6 g/kg, a total nitrogen content of 1.32 g/kg, a total phosphorus content of 1.84 g/kg, a pH of 7.0, a soil bulk density of 1.30 g/cm^2, a field water holding capacity of 43.54%, and a saturated water content of 37.29% (mass ratio).

II.Ⅱ EXPERIMENTAL DESIGN

The rice variety used in the experiment was "Longping Two Excellent 688", and the seedlings with similar growth were transplanted on May 20, with 10 rows in each plot (area 2.5×4m), 16 holes in each row, and 3~4 plants in each hole, and the harvest was made on September 8, and the time of each fertility period was as shown in Table Ⅰ, with the full-life span of 111 days.

TABLE Ⅰ DIVISIONS OF RICE FERTILITY DURING 2022

Reproductive period	Regreening stage	Tillering stage	Jointing and booting stage	Heading and flowering period	Milky stage	Yellow mature period
Time (month/day)	May 20-June 9	June 11-July 10	July 11-July 24	July 25-August 3	August 4-August 16	August 17-September 8

The mild (90%-0-40), moderate (80%-0-40) and severe (70%-0-40) water deficit treatments were set up at the tillering stage, nodulation and pregnancy stage, spike and flowering stage and milky ripening stage, respectively, and fully irrigated (100%-10-40) was used as the control, for a total of 13 irrigation treatments, with three replications of each treatment set up in a total of 39 plots, and the experiment was conducted in a randomized block design with a randomized Arrangement. The upper limit of irrigation for mild (L), moderate (M) and severe (H) water deficit treatments was the saturated soil water content (i.e., huada water, described as water layer thickness 0), and the lower limit of irrigation was 90%, 80%, and 70% of the saturated soil water content, respectively. When the soil moisture content reaches the lower limit of irrigation, it needs to be irrigated to the upper limit (i.e., the saturated water content, and the depth of the water layer 0 mm), and the upper limit of irrigation of the control treatments was 10 The upper limit of irrigation for the control treatment was 10 mm, and the lower limit was when the soil moisture content was 100%. All treatments maintained 50 mm water layer during soaking period, 30 mm water layer during greening period, and naturally fell dry during yellow ripening period, as shown in Table Ⅱ.

TABLE Ⅱ WATER CONTROL STANDARDS FOR DIFFERENT GROWTH STAGES OF RICE

Treat ment	Upper and lower limits of irrigation (% represents soil water content, unitless numbers represent water depth)						
	Field stage	Regree ning stage	Tillering stage（T）	Jointing stage（J）	Heading stage（H）	Tilky stage （M）	Yellow mature stage
CK	50	30	100%-10-40	100%-10-40	100%-10-40	100%-10-40	dry naturally
TL TM	50	30	90%-0-40 80%-0-40	100%-10-40	100%-10-40	100%-10-40	dry naturally

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TH			70%-0-40				
JL				90%-0-40			
JM	50	30	100%-10-40	80%-0-40	100%-10-40	100%-10-40	dry naturally
JH				70%-0-40			
HL					90%-0-40		
HM	50	30	100%-10-40	100%-10-40	80%-0-40	100%-10-40	dry naturally
HH					70%-0-40		
ML						90%-0-40	
MM	50	30	100%-10-40	100%-10-40	100%-10-40	80%-0-40	dry naturally
MH						70%-0-40	

Note: 90%-0-40 means that the lower limit of irrigation is 90% of the saturated water content of the soil, and the upper limit is 0cm water layer. In case of rain, the field water layer is kept 40mm (automatically controlled by the overflow port of the test plot).

The agronomic measures were the same in the experimental plots, with timely weeding to avoid weeds jeopardizing the growth and development of rice, and following the local traditional methods of controlling rice pests and diseases to ensure stable rice yield. Fertilizers were applied consistently in all treatments, and the fertilizers were applied according to different ratios. Nitrogen fertilizer (N 110 kg/hm^2) was applied according to the ratio of base fertilizer, tiller fertilizer, flower-promoting fertilizer, and flower-protecting fertilizer of 4.5:2:1.5:2, phosphorus fertilizer (P_2O_5 45 kg/hm^2) was applied once as base fertilizer, and potash fertilizer (K_2O 80 kg/hm^2) was applied twice as base fertilizer and at 8.5 years of age (the stage of young spikelets), with a ratio of 1:1 before and after the fertilization. The ratio was 1:1. The basal fertilizer was applied on May 8, 20, transplanting on May 20, tiller fertilizer on June 9, flower-promoting fertilizer on July 9, and flower-protecting fertilizer on July 22, 2022, and the fertilizer was applied at the same time.

II.Ⅲ MAIN OBSERVATION INDEXES AND METHODS

(1) Soil moisture measurement: The soil water potential was monitored daily at 8:00 and 18:00 using a negative pressure meter produced by Beijing Autostar Company, and changes in the depth of the water layer were measured with a straightedge, and when the lower limit of irrigation was reached in each treatment, water was manually irrigated to the upper limit.

(2) Water consumption: The amount of water used for each irrigation of a large field plot is measured by means of a water meter.

(3) Rice yield: After the rice matures, each plot is tested separately to determine the effective number of spikes, the number of grains in a spike, the mass of 1,000 grains and the fruiting rate of rice, and to calculate the rice yield.

(4) Water use efficiency :

$$WUE = \frac{Y}{ET} \quad (1)$$

Where: WUE— water use efficiency, kg/m^3 ; Y— yield, kg ; ET— total water consumption over the whole reproductive period,m^3.

II.Ⅳ DATA PROCESSING METHODS

Data were processed and plotted using Excel 2016 and SPSS 23.0 and analyzed for significance using LSD method.

III. RESULTS

III. Ⅰ EFFECT OF WATER DEFICIT ON WATER CONSUMPTION CHARACTERISTICS OF RICE DURING ITS REPRODUCTIVE PERIOD

As can be seen from Figure 1(a), water consumption of rice at all fertility stages decreased with the increase of water deficit, and at three water deficit levels at tillering stage, the water consumption of TL, TM and TH treatments decreased by 23.08%, 37.73% and 46.15%, respectively, compared with CK, and the differences with CK were all at a significant level ($P<0.05$); after the resumption of normal irrigation, the water consumption at the jointing stage of each water deficit treatment were all After resuming normal irrigation, the water consumption at the tasseling stage of each water deficit treatment was not significantly different from that of CK ($P>0.05$), while the water consumption at the tasseling stage and milk ripening stage of TM and TH treatments were significantly lower than that of CK ($P<0.05$). As can be seen from Figure 1(b), at the three water deficit levels at the nodulation stage, the water consumption of JL, JM and JH treatments were

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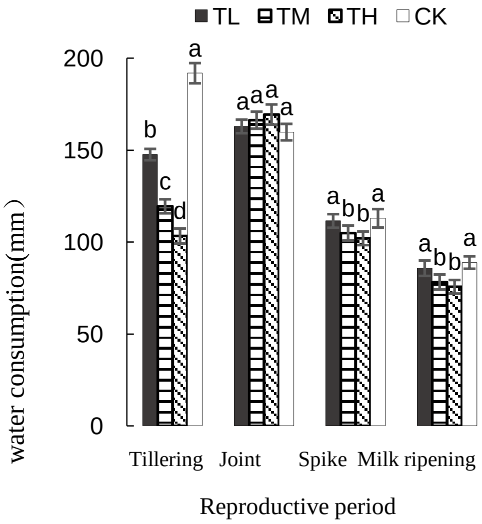
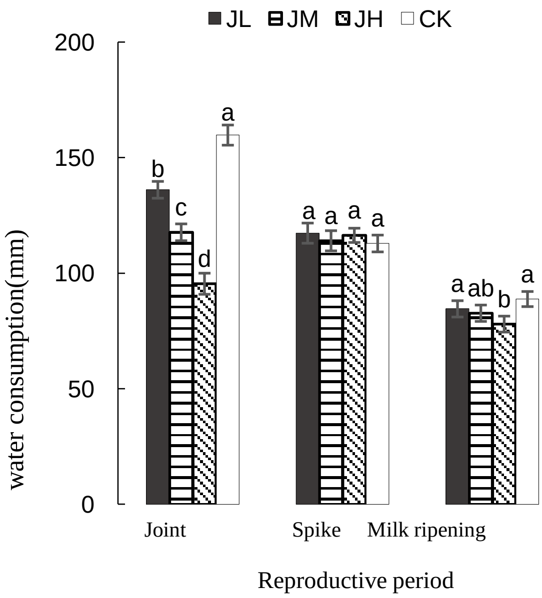
significantly lower than that of CK by 14.81%, 26.32% and 40.25%, respectively (P<0.05); after resumption of normal irrigation, the water consumption at tasseling and milk ripening of the three treatments was not significantly different from that of CK (except for water consumption at milk ripening in the JH treatment). As can be seen from Fig. 1(c), at the three water deficit levels at tasseling stage, the water consumption of HL, HM and HH treatments were significantly reduced by 28.05%, 38.00% and 48.78%, respectively, compared with that of CK (P < 0.05); after normal irrigation was resumed at milk ripening stage, the water consumption of the three treatments were not significantly different from that of CK (P > 0.05). As shown in Figure 1(d), the water consumption of the water deficit treatments at milk ripening stage was significantly reduced by 31.05%, 46.01% and 43.55% (P < 0.05) with the increase of the degree of water deficit, in order of magnitude, compared with that of CK.

In summary, the water consumption of the water deficit treatments at the spike and milky stage was reduced to a greater extent, followed by the tillering stage and the minimum at the nodulation stage; the water consumption of the moderate water deficit at different fertility stages was able to return to the normal level after re-watering, while that of the severe water deficit treatment was still significantly lower than that of the CK after re-watering.

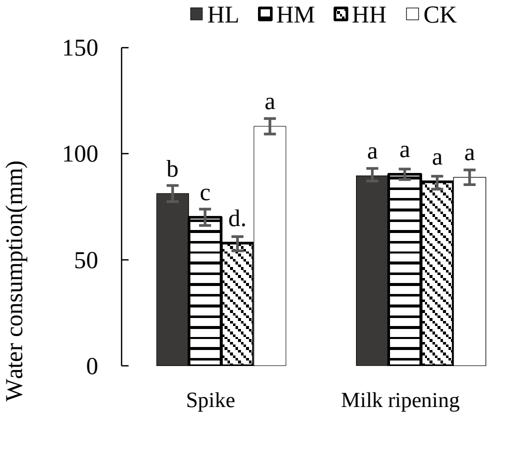
FIGURE Ⅰ EFFECT OF REGULATED DEFICIT IRRIGATION ON STAGE WATER CONSUMPTION OF RICE



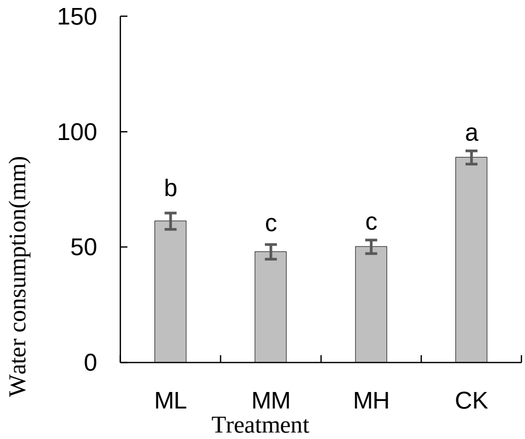
a.Water deficit during tillering stage



b.Water deficit during jointing stage



c.Water deficit during heading period



d.Water deficit during milkystage

III.Ⅱ IMPACT OF WATER DEFICIT ON RICE YIELD AND ITS COMPONENTS

As shown in Table 3, water deficit treatments at tillering stage significantly affected the effective number of spikes in rice, where TL, TM and TH treatments significantly reduced the effective number of spikes by 5.43%, 11.63% and 17.83%, respectively, compared with CK ($P < 0.05$), and H at nodulation stage and M and H at tasseling stage also significantly reduced the effective number of spikes by 93.80%, 93.80% and 91.47%, respectively, compared with CK ($P < 0.05$), and other water deficit treatments had no significant effect on the number of effective spikes in rice ($P > 0.05$). Moisture deficit at the tasseling stage had a greater effect on the number of grains in a spike of rice, in which the HL, HM and HH treatments were significantly reduced by 4.47%, 7.84% and 8.46%, respectively, compared with CK ($P < 0.05$), and the H treatments at the nodulation stage and milky maturity stage were 96.32% and 94.99%, respectively, of the CK, which were at the level of significance compared with CK ($P < 0.05$), whereas the L treatments at the tillering stage significantly increased the number of grains in a spike of rice number of grains and had the largest number of grains in spikes, which increased by 18.34% ($P < 0.05$) compared with CK.The L and M treatments at the tillering stage increased rice thousand grain quality by 9.01% and 9.64%, respectively, compared with CK ($P < 0.05$), but the more severe water deficits at all fertility periods except the tillering stage significantly affected rice thousand grain quality ($P < 0.05$), with the MH treatment having the greatest effect, which was only 95.11% of that of CK. Moisture deficit at milky stage significantly affected rice fruiting rate, in which ML, MM and MH treatments were 98.05%, 96.59% and 95.23% of CK, respectively ($P < 0.05$), while H treatment at the nodulation stage also significantly reduced rice fruiting rate ($P < 0.05$). The L treatment at tillering stage effectively increased rice yield by 21.47% ($P < 0.05$) compared with CK, and the more severe water deficit at different fertility stages significantly reduced rice yield, with the JM, TH, MH, JH, HM and HH treatments only 93.58%, 92.85%, 85.91%, 85.00%, 83.11% and 80.22% of CK, respectively ($P < 0.05$), while the other water deficit treatments did not differ significantly ($P > 0.05$) from CK and had no significant effect on rice yield.

Ⅲ RICE YIELD AND ITS COMPONENTS UNDER WATER DEFICIT CONDITIONS AT DIFFERENT GROWTH STAGES

Treatment	Effective panicle number/ ($10^4 \cdot hm^{-2}$)	Number of grains per spike/ ($grain*spike^{-1}$)	Thousand grain mass/g	Seed setting rate/%	Production/ ($t \cdot hm^{-2}$)
TL	203.35±11.5c	86.14±2.87a	29.87±0.54a	95.06±1.73ab	11.03±0.75a
TM	190.00±10.0d	72.32±0.61c	30.04±1.11a	94.83±1.37ab	8.71±0.88cd
TH	176.65±15.3e	81.45±0.53b	27.84±0.90b	94.51±0.38ab	8.43±0.21d

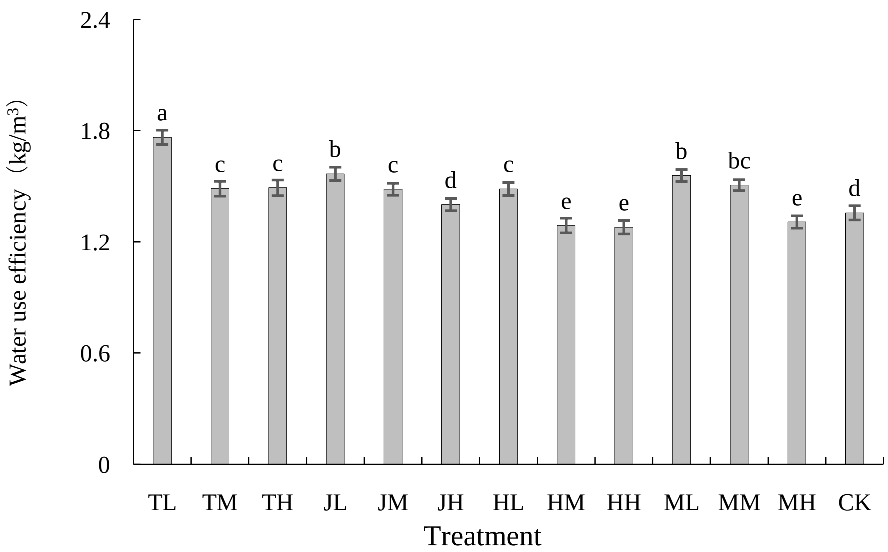
JL	215.00±10.0ab	73.77±0.96c	27.63±0.78b	95.24±0.29a	9.27±0.37b
JM	206.65±5.8bc	72.48±1.47c	27.14±0.50bc	94.15±0.71ab	8.50±0.03d
JH	201.65±5.8c	69.14±0.64d	26.61±0.68cd	93.67±0.64bc	7.72±0.24ef
HL	215.00±10.0ab	69.54±0.74d	27.86±0.37b	95.17±0.21a	8.81±0.24bc
HM	201.65±5.8c	67.08±0.50e	26.58±0.88cd	94.50±0.40ab	7.55±0.25ef
HH	196.65±5.8cd	66.64±0.93e	26.52±0.27cd	94.34±0.26ab	7.28±0.22f
ML	221.65±5.8a	73.19±0.21c	28.09±0.31b	93.52±0.94c	9.47±0.29b
MM	216.65±15.8ab	72.78±0.99c	27.85±0.22b	92.13±0.34d	8.99±0.29bc
MH	211.65±5.8b	70.11±0.74d	26.06±0.52d	90.83±1.40e	7.80±0.24e
CK	215.00±17.3ab	72.79±0.48c	27.40±0.58bc	95.38±0.60a	9.08±0.13bc

Note: Different Minuscule in the same column indicate significant difference at the level of P<0.05.

III. Ⅲ EFFECT OF WATER DEFICIT ON WATER USE EFFICIENCY IN RICE

As can be seen from Figure 2, the WUE of TL treatment was the largest and significantly higher than the other treatments at 1.76 kg/m3, which was 30.01% higher than that of CK ($P < 0.05$), whereas the WUE of MH, HM and HH treatments were significantly lower than that of CK ($P < 0.05$), and although the yield of TH, JM and JH treatments was significantly lower than that of CK, the water consumption of all of them was lower than that of CK, and the reduction of water consumption of TH, JM and JH treatments was greater than the reduction of yield compared with CK ($P > 0.05$), therefore, the WUE of TH, JM and JH treatments was higher than that of CK. JM and JH treatments the reduction of water consumption was greater than the reduction of yield, so the WUE of TH, JM and JH treatments was higher than CK, of which JH treatment was not significantly different from CK ($P > 0.05$).

FIGURE Ⅱ EFFECT OF WATER DEFICIENCY ON WATER USE EFFICIENCY OF RICE



IV. DISCUSSION

Exploring the water consumption pattern of crops under water deficit conditions is an important basis for formulating water-saving irrigation systems and improving water utilization efficiency [7]. The results of this study showed that the water deficit in all fertility periods can effectively reduce the water consumption of rice, of which the spike period and the milk ripening period reduce the magnitude is larger, this is because the spike period of vigorous plant growth, canopy cover is higher, while the temperature is higher, transpiration is larger, the water consumption is larger, water stress can significantly reduce the water consumption, and milk ripening period of plant growth basically stopped, and the temperature is lower in this period, the water deficit treatment needs a longer time to reach the lower limit of irrigation, so the two fertility periods of water deficit can significantly reduce water consumption, and the

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water loss in this period of water loss can be reduced. At the milking stage, plant growth basically stopped, and the temperature was low in this period, so the water deficit treatment needed a longer time to reach the lower limit of irrigation, so the water consumption of the two fertility stages decreased more. The water consumption of moderate water deficit at different fertility stages could return to normal level after re-watering, while the water consumption of severe water deficit treatment was still significantly lower than that of CK after re-watering, which might be due to the inhibition of some physiological functions caused by the severe water stress, and therefore could not return to normal level after re-watering.

In this experiment, rice consumed the highest amount of water at the tillering stage, which was consistent with the findings of Worksop [8], while Chen [9] found the highest water consumption at the pulling stage, mainly due to its division of the tillering stage into three stages, which was not divided in this experiment. In this study, it was found that the water consumption of all three water deficit levels at tillering stage differed from CK at a significant level ($P < 0.05$), and after resumption of normal irrigation, the water consumption at the pulling stage of all the water deficit treatments did not differ significantly ($P > 0.05$) from CK.It may be due to the fact that after the water deficit at the tillering stage, the amount of water required to irrigate was higher when the first irrigation was resumed to the upper limit of normal irrigation at the pulling stage, but thereafter irrigation was reduced by the effect of water stress at the tillering stage which had a posterior effect on water consumption, so that by combining the first irrigation at the pulling stage with the subsequent consumption, the difference between the consumption of water at that stage and that at CK was not significant.Water is a major factor affecting rice yield. In this study, it was found that mild water deficit at tillering stage significantly increased rice yield and moderate water deficit at all fertility stages did not significantly reduce rice yield, which was inconsistent with the findings of Wang et al [10], which might be due to the fact that the lower limit of soil water potential set by them was lower than the lower limit of water control in this study, which resulted in a significant reduction in the number of effective spikes.The results of Peng et al[11]showed that water deficit at the tassel-flowering stage had a greater effect on rice yield, which is consistent with the results of the present study. It has been shown[12-13] that rice cultivation practices, irrigation patterns and nitrogen application affect rice water use efficiency. The present study showed that conducting moderate water deficit at all fertility stages could effectively improve rice water use efficiency, which is consistent with the findings of Yang et al[6]. Therefore, moderate water deficit at appropriate fertility stages can effectively improve rice yield and water use efficiency.

V. RESULT

（1）Water deficit was effective in reducing water consumption at the deficit stage, and water consumption at all fertility stages decreased with the increase of water deficit, among which the reduction was greater in the water deficit treatments at the tasseling stage and milky stage, followed by the tillering stage, and the smallest at the nodulation stage.

（2）Water deficit at the tillering stage mainly affected the effective number of spikes of rice, water deficit at the tasseling stage had a greater effect on the number of grains in spikes of rice, and water deficit at the milk ripening stage significantly affected the fruiting rate of rice; whereas, mild water deficit at the tillering stage significantly increased the number of grains in spikes and the quality of 1,000 grains of rice, and was effective in increasing the yield of rice.

（3）Water use efficiency was greatest in the light water deficit treatment at tillering stage, whereas the medium and heavy water deficit treatments at tasseling stage and the heavy water deficit treatment at milking stage were significantly lower than the fully irrigated treatment.

REFERENCES

- Cao X C, Liu J, Wu M Y, et al.Water foot printing to analyze the spatial and temporal patterns and driving mechanisms of water scarcity on cropland in China[J].AgriculturalEngineering,2019,35(18): 94-100.
- Zhang J K, Liu C S, Xu L, et al.Exploring the development mode of water-saving irrigation in Huaibei Plain, Anhui Province, China [J]. Anhui Agricultural Science,2019,47(07):215-217+224.
- Zhu W, Zhang X B, Geng X Y, et al.Progress in the study of salinity and drought affecting rice root morpho physiology and yield formation and their mechanisms[J].Chinese rice,2023,29(03):34-40+45.
- Li C Y, He J, Zhao F, et al.Effects of different water and fertilizer regulation on rice yield, dry matter and soil fertility [J].water-savingirrigation,2022,325(09):108-11

3+123.
- Ma R J, Chang Y Q, Jin W J, et al.Progress on the mechanism of efficient water utilization in rice [J].Chinese rice,2019,25(03):15-20.
- Yang Y, Zhang Z X, Zhen E N, et al.Effect of water deficit on fluorescence parameters, yield and water use efficiency of rice in cold regions [J].Journal of Irrigation and Drainage,2018,37(10):35-41.
- Zhao L W, Zhao W X, Ji X B.Distinction between crop transpiration and soil evaporation and crop water consumption pattern in the middle reaches of the Heihe River desert oasis farmland in Northwest China [J].2015,35(04):1114-1123.
- Yun N H.Regulation of yield and photosynthetic characteristics by water-fertilizer coupling in direct seeded rice from cold black soil [D].Harbin: Northeast Agricultural University,2018.
- Run C.Response mechanism of water depletion process and yield formation of rice in black soil area [D].Harbin: Northeast Agricultural University,2019.
- Wang C Y, Wang B L, Zhang W X, et al.Effect of drought stress period on rice yield and yield traits [J].China Agronomy Bulletin,2008,24(2):160-166.
- Peng S Z, Cai M, Kong W L, et al.Effect of water deficit on dry matter and yield of rice at different fertility stages [J].Water Resources and Water Engineering,2012,23(1):10-13.
- HAO L, KELIN H,WEI Q,etal.Ground cover rice production system reduces water consumption and nitrogen loss and increase water and nitrogen use efficiencies[J].Field Crops Research,2019,233:70-79.
- Men X Y, Zhou L Y, Zhang Z X, et al.Effect of different irrigation patterns on growth, water and radiation use efficiency of rice [J].Agricultural Machinery,2019,50(11):285-292.