WATER EFFICIENT IRRIGATION AND ENVIRONMENTALLY SUSTAINABLE IRRIGATED RICE PRODUCTION IN CHINA

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ABSTRACT

Rice is one of the most important food crops contributing over 39% of the total food grain production in China. Out of 113 million hectares of area sown under food crops 28% is covered by rice. The traditional irrigation regime for rice, termed as "continuous deep flooding irrigation" was applied in China before 1970s. A tremendous amount of water was used for the rice growing and only a low yield of rice was obtained under this regime.

Since 1980s, the industry water supply, urban and rural domestic water consumption have been increasing continuously. The shortage of water resources became an important problem and many water efficient irrigation regimes for rice have been tested, advanced, applied and spread in different regions of China. Based on the results of experiment and the experience of spread of these new irrigation regimes, the following three main kinds of water efficient irrigation regimes were found to be contributing to the sustainable increased water productivity viz. (1) combining shallow water depth with wetting and drying, (2)alternate wetting and drying and (3) semi-dry cultivation. In this paper, the standard of controlling field water, conditions and the attention points of the application for the three regimes are introduced and explained.. The causes of sustainable increase in water productivity and the environmental impacts by adopting these regimes are analyzed and discussed.

1. INTRODUCTION

China is a major rice producing country having about 31 million ha under rice paddy cultivation. In 1999, the total rice yield reached 200.5 million tons, which account for 39% of the total grain production of the country [2]. A tremendous amount of water is used for the rice irrigation under the traditional irrigation regime (TRI) termed as "continuous deep flooding irrigation regime" in major part of the rice growing regions in China before 1970s. Since 1980s, the industrial water supply, urban and rural domestic water consumption increased continuously, and there is a decreasing trend in water resources availability year by year. And then, the shortage of water resources has become an important problem. With the hard work of sagacity of the central government, the water efficient irrigation regimes (WEI) for rice have been researched since 1980s, and many of those were adopted in different rice growing regions in China, aiming to increase the water and land productivity and environmental improvement [5][11][12][16]. The area adapted under WEI for rice amount to about to about 5.7 million ha in 1997[17]. Based on the analysis of experimental data and the results of investigation from some typical rice growing regions adopting WEI, three essential kinds of WEI for rice in China were summed up and the standards of field water management for these regimes were presented by the author [11][12]. The results and mechanism of increasing in water productivity and the environmental impacts by applying WEI are described and discussed.

2. WATER EFFICIENT IRRIGATION REGIMES FOR RICE AND THEIR FIELD WATER MANAGEMENT

More than 10 water efficient irrigation regimes (WEI) for rice have been adopted in China for the different conditions of weather, soil, topography, species of rice, water resources and irrigation projects etc. Among them, 3 most important regimes were summed up [11]. These regimes and their basic features of field water management are as follows:

2.1 Combining shallow water depth with wetting and drying (SWD)

In China, the standards of the following concerned terms have been presented in the "National Specification of Irrigation Experiment"[19]. Shallow water depth: 10-60 mm water depth on the surface of soil. Deep water depth: the depth of water depth is more than 60 mm. Wet: the upper limit of field water is 10 mm water depth and the lower limit is that the soil moisture content in root zone is equal to 80% of the saturated moisture content (SMC). Dry: The soil moisture content in root zone is lower then 80% of SMC. The feature of SWD is comprehensive application of shallow water depth, wetting and drying in the entire growing season of rice. This regime has been spread widely in the southern provinces of China since 1980s. The standards of field water control of this region applied in Guangxi Autonomous Region is South China is shown in Table 1 and Fig. 1 (a)[11][12].

Table 1. Field water control with SWD in Guangxi Region

Growth stage	Standard of field water control (mm)			State of field water
	Lower limit (Begin irrigation)	Upper limit (After irrigation)	Extra limit (Begin draining)	
Transplanting	15	20	20	Shallow water depth
Revival of green	20	40	50	Shallow water depth
Early and middle stages of tillering	80% SMC*	10	40	Wet
Late stage of tillering	60% SMC	20	40	Drying field
Elongating to flowering	10	40	70	Shallow water depth
Milk ripening	80%SMC	10	50	Wet
Yellow ripening	Dry field			Dry field

* SMC is the saturated moisture content.

Based on the standards of field water control, when the depth of pounded water or average moisture content in the root zone falls to the lower limit level, the paddy field is filled to the upper limit level by irrigation. The extra limit levels are set up for storing more precipitation and drainage occurs when the water level goes beyond the extra limit level.

2.2 Alternate wetting and drying (AWD)

AWD has been spread both in the south, north and north—east of China. The feature of field water control for AWD is that paddy field is intermittently submerged and no water depth during the beginning of tillering to the end of milk ripening stage and the standards of water control are similar to SWD for other stages.

Two kinds of AWD——long term alternate wetting and drying (LAWD) and short term alternate wetting and drying (SAWD) have been adopted for different conditions [11]. For LAWD, every 6-8 days irrigate once, the water quantity for each irrigation is 50-60 mm and the water depth after irrigation is formed 30-40 mm, them, dry naturally. The soil moisture content before irrigation is 70%-80% of saturated moisture content. The paddy field is submerged for 4-5 days and no water cover for 2-3 days. For SAWD, every 4-5 days irrigate once, the water quantity of each irrigation is 30-40 mm and the water depth after irrigation is maintained 20-30 mm, then allowed to dry naturally. The soil moisture content before irrigation is 80%-90% of SMC. The paddy field is submerged for 3-4 days and no water depth for 1-2 days.

Based on the experimental data and the results of application of AWD in Hubei Province and Guangxi Autonomous Region, the recommended standards of field water control corresponding to the AWD for the South China are given in Table 2 and Fig. 1 (b)[5][11][12][14][16].

Table 2. Recommended standards of field water control (mm) with AWD for South China

Growth stages	Early rice			Middle rice			Late rice		
	Lower limit	Upper limit	Extra limit	Lower limit	Upper limit	Extra limit	Lower limit	Upper limit	Extra limit
Revival of green	0	30	50	0	40	60	0	40	60
Early and mid Stages of tillering	0	30	50	0	40	60	0	40	60
Late stage of tillering	70%SMC	20	50	70%SMC	20	60	80%SMC	20	60
Elongating and booting	80%SMC	30	80	80%SMC	30	80	80%SMC	30	80
Shooting and flowering	90%SMC	30	80	90%SMC	30	80	80%SMC	30	80
Milk ripening	70%SMC	20	50	70%SMC	20	50	70%SMC	20	50
Yellow ripening	Dry field			Dry field			Dry field		

2.3 Semi-dry cultivation (SDC)

This regime was presented based on experiments and practices over past 10 years. There is a great difference of field water control between SDC and the above—mentioned regimes (SWD and AWD). For SDC, the water depth is maintained only in the revival of green or revival of green to the middle stage of tillering. There is no water depth on paddy field in the other stages in entire growing season. SDC have been adopted in some irrigation districts in the East and South China. The standards of field water controlling in Shangdong Province in East China is shown in Table 3 and Fig. 1 (c)[11][16].

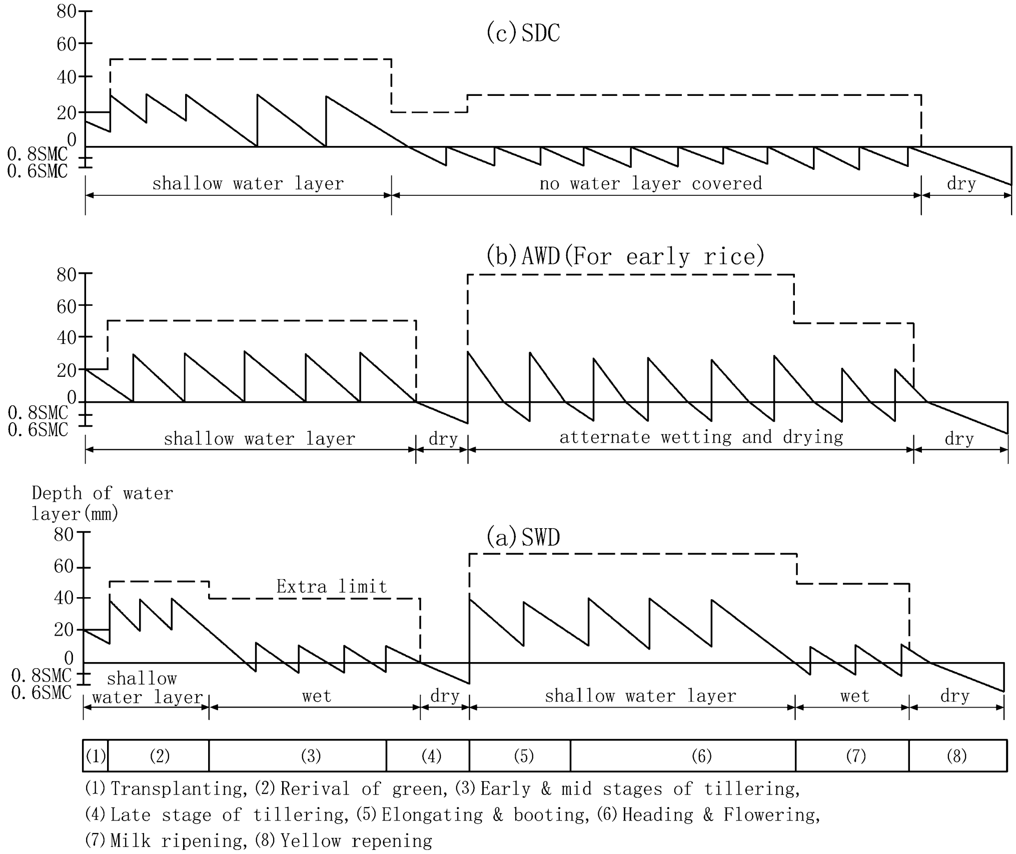

Fig.Graphical discrption of different water efficient irrigation regimes

Table 3. Standards of field water control (mm) with SDC in Shangdong Province

Growth stages	Standards of field water control (mm)			State of field water
	Lower limit (Begin irrigation)	Upper limit (After irrigation)	Extra limit (Begin draining)	
Transplanting	5	15	20	Shallow water depth
Revival of green	15	30	50	Shallow water depth
Early & mid stages of tillering	0	30	50	Shallow water depth
Late stage of tillering	70SMC	0	20	No water depth
Elongating to flowering	75%SMC	0	30	No water depth
Milk ripening and early stage of yellow ripening	70SMC	0	30	No water depth
Mid & late stages of yellow ripening		Dry field		Dry field

SDC is an innovative irrigation regime over the traditional methods of submergence irrigation for rice. Although the area of spreading SDC is the smallest among 3 main water-efficient irrigation regimes in China, this regime will deserve further studying and spreading due to high water use efficiency.

3. IMPACT OF WATER EFFICIENT IRRIGATION ON IRRIGATION WATER USE, RICE YIELD AND WATER PRODUCTIVITY

3.1 Irrigation water use under different irrigation regimes

Based on the results of experiment and investigation from 15 provinces (autonomous regions), in comparison with TRI, the irrigation water use was reduced by 3% -18%, 7%-25% and 20%-50% under SWD AWD and SDC respectively [11][12]. The values of net irrigation water use with different irrigation regimes from the experimental data in 1997 to 1999 in Guilin City, Guangxi Region are shown in Table 4[14], whereas the values in 1998 from Hangzhou City, Zhejiang Province are shown in Table 5[26].

Table 4. Net irrigation water use (M, m3/ha) under different irrigation regimes (Guangxi)

Year	Term	Early rice				Late rice				Whole year		
		TRI	SWD	AWD		TRI	SWD	AWD		TRI	SWD	AWD
1997	M (m^3/ha)	2390	2190	1785		8100	7890	7385		10490	10080	9710
	Percentage	100	91.6	74.7		100	97.4	91,2		100	96.1	92.6
1998	M (m^3/ha)	2750	2439	2415		6743	5867	6341		9493	8306	8756
	Percentage	100	88.7	87.8		100	87.0	94.0		100	87.5	92.2
Average	M (m^3/ha)	2570	2312	2100		7422	6879	6863		9992	9193	9233
	Percentage	100	90.0	81.7		100	92.7	92.5		100	92.0	92.4

Table 5. Net irrigation water uses under different irrigation regimes in 1998 (Zhejiang)

Rice Type	Early rice				Late rice				Whole year		
Irrigation regimes	TRI	SWD	SDC		TRI	SWD	SDC		TRI	SWD	SDC
Irrigation Water use (m^3/ha)	2607	2205	1645		3765	3195	2499		6372	5400	4144
Percentage (%)	100	84.6	63.1		100	84.8	66.4		100	84.7	65.0

3.2 Rice yields and water productivity under different irrigation regimes:

Table 6 and Table 7 give the values of the rice yields and the water productivity WP_1—yield per unit of water consumption and WP_2 yield per irrigation water use with different irrigation regimes [5][13][26]. These values indicate that the rice yield could be increased only marginally i.e. less than 9%, but the water productivity could be increased remarkably due to the decrease of water consumption and irrigation water use through WEI. The water productivity due to water consumption WP_1 and to irrigation water use WP_2 can be increased by 11%-56% and 11-69%, respectively. Several other reports in the country has also claimed that WP_1 and WP_2 could be increased by 20%-30% and 30-50%, respectively, through applying WEI [5][11][12][13][14][16][22].

Table 6. Rice yields (kg ha^{-1}) of different irrigation regimes

Province	Year	Rice Type	Yield			
			TRI	SWD	AWD	SDC
Hubei	1997	Middle	9969		9455	
	1998	Middle	7767		8790	
	Average		8868		9123	
	Percentage of average		100		102.9	
Guangxi	1997	Early	6050	6147	6251	
	1997	Late	4335	4424	4380	
	1998	Early	5766	5772	5919	
	1998	Late	7484	7970	7995	
	1999	Early	5504	6269	6416	
	1999	Late	7484	7970	7995	
	Average		6104	6425	6493	
	Percentage of average		100	105.3	106.4	
Zhejiang	1998	Early	6075	6306		6746
	1998	Late	6363	6326		6746
	Average		6219	6316		6746
	Percentage of average		100	101.6		108.5

Table 7. On-farm WP (kgm^{-3} water) for different irrigation regimes

Province	Year	Rice type	WP^{*}_{1}				WP^{**}_{2}			
			TRI	SWD	AWD	SDC	TRI	SWD	AWD	SDC
Hubei	1997	Middle	1.022		1.017		1.588		1.784	
	1998	Middle	0.856		1.122		1.922		3.381	
	Average		0.939		1.070		1.755		2.583	
	Percentage of average		100		114.0		100		147.2	
Guangxi	1997	Early	0.85	1.05	1.20		2.53	2.81	3.50	
	1997	Late	0.40	0.45	0.52		0.54	0.56	0.59	
	1998	Early	0.87	0.88	1.18		2.10	2.37	2.45	
	1998	Late	0.51	0.61	0.57		1.11	1.34	1.26	
	1999	Early	0.80	0.85	1.00		1.47	1.70	2.27	
	1999	Late	0.44	0.50	0.68		1.04	1.29	1.86	
	Average		0.65	0.72	0.86		1.47	1.68	1.99	
	Percentage of average		100	111	132		100	114	136	
Zhejiang	1998	Early	1.168	1.371		1.775	2.33	2.86		4.10
	1998	Late	0.994	1.169		1.599	1.69	1.98		2.70
	Average		1.081	1.270		1.687	2.01	2.42		3.40
	Percentage of average		100	117.5		156.1	100	120.4		169.2

*WP_1—yield per water consumption
*WP_2—yield per irrigation water use

4. SELECTION OF WATER EFFICIENT IRRIGATION REGIMES AND PRECAUTIONARY MEASURES:

4.1 Selection of water efficient irrigation regimes

The adopted regime may by selected based on the conditions of texture, chemical properties and fertility of soil, topography, ground water table, meteorology, and variety of rice and water sources. Generally, SAWD may be selected in the conditions of low land, heavy-textured soil, shallow ground water table and fertile field with thick and strong stem of rice, and LAWD may be selected in the contrary conditions. SWD can be selected in all of the different conditions, but the depth of water depth when submergence should be shallow and the duration of wetting and drying should be longer in case of low land, heavy-textured soil, high ground water table and fertile field with thick and strong stem of rice than that in the contrary conditions. The depth of extra limit after raining should be deeper in the conditions of light textured soil, low ground water table and lack of water resources than in the contrary conditions [11][12][13][15].

Some special regimes should be selected in the special conditions. For example, the continuous flooding regime may be used on the rice field with saline soil for leaching soil salt and for controlling salinity in the soil.

As per the results of experiments and practices [16]. SDC can be used in different types of soil. It is an innovative regime over the other irrigation regimes for rice. This regime deserves further studying and spreading due to high water use efficiency, beneficial environmental impact and high yield.

5. 4. Precautionary measures for application of WEI

Some new problems causing decrease in rice yield may arise while applying WEI. One must attend to the following point for resolving these problems to avoid the decrease in rice yield [10][11][12][13][14]. First, no lack of water at the time when irrigation is applied. Second, the fertilization method of raising the fertilizer efficiency may be adopted during the periods of no standing water on the paddy field. The chemical fertilizer should be evenly distributed to the soil before irrigation and the field should be irrigated slowly. Third, weeds grow fast, since the paddy field is wetted and dried intermittently. Therefore, measures to control weeds (including the application of chemical weed killer) should be adopted. Fourth, the adequate water depth should be maintained through irrigation for increasing the heat capacity to avoid the harm to rice by low temperature when the air temperature is lower than 12 in growing season of rice, or lower than 20 in the period of differentiation of young ear of rice, or when a cold wind blows over. On the other hand, the adequate water depth should be maintained for increasing the heat capacity to avoid the harm to rice by high temperature when the air temperature is higher than 35 C.

6. CAUSES OF HIGH WATER PRODUCTIVITY BY USING WATER EFFICIENT IRRIGATION REGIMES

The causes of high water productivity by using water efficient irrigation regimes are that the irrigation water requirement is reduced remarkably, and the rice yield is increased. It, at least, doesn't reduce yields.

5.1 Causes of the reduction of irrigation water requirements

The causes of the reduction of irrigation water requirements by using WEI are that the percolation and seepage are decreased remarkably, the evapo-transpiration is decreased and the utilization of rainfall is increased. The approximate ranges are as follows [11][12]: (1) percolation and seepage can be decreased by 30%-65% when using SDC and decreased by 20%-35% when using SWD and AWD, (2) evapotranspiration can be decreased by 3%-10% when using SWD and decreased by 5%-15% when using AWD and SDC, (3) the rainfall utilization can be increased by 5%-15% when using WEI. For instance, the values of the water balance components in paddy fields under different irrigation regimes at two sites in the southern China are shown in Table 8 and Table 9[26].

Table 8. Water consumptions by different irrigation regimes (Zhejiang, 1998)

Rice type	Early rice			Late rice		
Irrigation regime	TRI	SWD	SDC	TRI	SWD	SDC
ET (mm)	370	350	310	492	440	360
ET (%)	100	94.6	83.8	100	89.4	73.2
Percolation F (mm)	150	110	70	148	101	62
F (%)	100	73.3	46.7	100	68.2	41.9
Water consumption ET+F (mm)	520	460	380	640	541	422
ET+F (%)	100	88.5	73.1	100	84.4	65.9

Table 9. Components of water balance (mm) in middle rice fields (Hubei 1998)

Growth stages	ET		Percolation		Rain utilized		Irrigation water use	
	TRI	AWD	TRI	AWD	TRI	AWD	TRI	AWD
Green revival	33.0	32.6	26.2	26.2	17.7	17.7	40	40
Early and mid tiller	78.5	72.6	45.9	35.3	36.3	36.3	70	50
Late tiller	42.0	46.3	34.0	21.5	36.2	36.2	65	70
Elongating and booting	149.4	137.1	75.6	51.8	84.0	84.0	130	100
Shooting and flowering	118.6	108.6	68.5	45.1	195.7	219.0	355	0
Milk ripening	93.1	81.7	37.0	22.6	28.2	80.1	50	0
Yell. ripening	93.5	90.4	12.2	11.9	42.7	42.7	0	0
Whole season	608.1	569.3	299.4	214.4	440.8	516.0	390	260
Percentage (%)	100	93.6	100	71.6	100	117.3	100	66.7

5.1.1 Causes of reducing percolation and seepage:

The reduction of percolation and seepage results from two ways. (1) The duration of no water depth and unsaturated condition in paddy field is longer under WEI than that under TRI. (2) The depth of water depth is shallower under WEI than that under TRI. Theoretically, under WEI, the percolation and seepage are reduced due to the above-mentioned two conditions. The measurement of data can also prove this situation. For example, the measured values of percolation rate from paddy fields in hilly land in Hubei Province under different water conditions of soil surface are shown in Table 10. [14]

Table 10. Percolation rate under different water condition on soil surface

Water condition on soil surface	Water depth (mm)				Days after the beginning of no water depth		
	>30	5-30	0-5		1	2	3
Percolation rate (mm/d)	3.8	3.2	2.8		2.0	1.5	1.1
Water condition on soil surface	Days after the beginning of no water depth						
	4	5	6		7	8	9
Percolation rate (mm/d)	0.9	0.7	0.5		0.3	0.2	0

The values in Table 10 have shown that the shallower the water depth, the smaller for percolation rate, and the shorter the days after the beginning of no water depth, the smaller for the percolation rate.

5.1.2 Cause of reducing evapotranspiration

Under WEI, most of the time the average soil moisture content in the rice root zone (0-40cm) is in 80%-90% of field capacity. This leads to the average soil moisture content in 0-5cm of surface layer to the level of below 50% of field capacity. Under this condition, the rice growth is not affected but the evaporation from soil in paddy field can be reduced by about 10-20%. This results in reduction of evapo-transpiration by 5-10%.

5.1.3 Cause of increasing utilization of rainfall

Though the extra limits (limits for spilling) with WEI are similar to those with TRI, the upper limits for irrigation of WEI are much lower than those for TRI. The capacity of paddy fields to store rainfall is increased greatly, and precipitation is fully utilized without hindering rice growth under WEI.

6.0 MAIN CAUSES OF GETTING BUMPER YIELD UNDER WATER EFFICIENT IRRIGATION REGIMES

6.1 Improving the condition of soil aeration

Traditionally, a proper rate of deep percolation is maintained to leach the poisonous matters within rice root zone resulting from an anaerobic condition and bring oxygen into rice root zone . However, WEI supplies enough oxygen to rice roots and induces an oxidized condition of soils. Table 11[23] shows that the longer the duration of the soil submerged by deep water, the lower the content of dissolved oxygen in soil water. The measured values of the oxidation—reduction potential under AWD conditions were always distinctly higher after about 30 days from transplanting than those under TRI. Normally, the oxidation—reduction potential decreases over rice growing season with TRI, but the experiment indicated that it increased with AWD [16], which implied that the soil aeration was improved.

Table 11. Relation between the content of dissolved oxygen in soil water and the days of submergence in deep-water depth (Zhejinag, 1994)

Days of submergence	1	2	3	4	5
Content of dissolved oxygen (mgl^{-1})	7.8	5.1	2.7	1.3	0.6

6.2 Promoting the action of micro-organisms and avoiding the accumulation of poisonous substances:

The action of microorganisms can be promoted and the accumulation of poisonous substances in the soil can be avoided by the favorable soil aeration. Based on the observed data from Changsha Irrigation Experiment Station in Hunan Province [4], the important microorganisms in the soil under WEI are more abundant than that under TRI (see page 10). The soil fertility can be increased through the transformation of organic matter by the abundance of important microorganisms.

6.3 Promoting the development of rice root:

The rice roots can grow well under oxidized paddy fields even under moderate water stress. The main zone of rice roots under WEI is deeper than that under TRI. During the root sampling, it was found that the rice roots distributed as a net within the top surface under TRI but branches well under WEI. Table 12 shows the conditions of both quantity and quality of rice roots under WEI and TRI [20]. The vitality of roots is promoted and the space for roots to assimilate nutrient and moisture is extended, which implied that there is an advantage in getting bumper yields under WEI.

Table 12. Number (No.stem^{-1}), color and diameter (mm) of rice roots under AWD and TRI (1986, Zhejiang)

Region	Total No. of all roots	No. of white Roots	No. of yellow roots	No. of black roots	Average diameter of roots
AWD	58	37	14	7	0.78
TRI	51	21	19	11	0.57

7. ENVIRONMENTAL IMPACT OF WATER EFFICIENT IRRIGATION FOR RICE

Based on the analyses of the results of experiments and practices, the major environmental impacts are presented below.

7.1 Reducing soil and water pollution:

20%-65% of the percolation and seepage water from rice fields can be reduced by using WEI. Fertilizer is lost with the percolation and seepage water. Based on the lysimetric data at the Guilin Station [1], fertilizer loss from late rice fields with percolation water under TRI is shown in Table 13. The values in Table 13 show that a great quantity of fertilizer, especially the nitrogenous fertilizer, is lost with the percolation water under TRI. Because the percolation and seepage water is reduced by 20-65% under WEI, fertilizer application can be reduced by using these new regimes.

Table 13. Fertilizer losses with percolation from late rice fields under TRI atGuilin (1992)

Kind of Nutrient	Rate of Percolation (mm/d)	Quantity of fertilizer loss with percolation water (mg/m^2)															
		August					September							October			
		10	14	18	21		5	9	14	18	21	24		1	7	11	
NH_4^+ (Nitrogenous nutrient)	3	9.6	10.5	9.1	11.9		8.7	8.6	9.3	8.7	10.4	9.4		10.4	9.2	9.4	
	6	17.9	18.4	16.9	18.2		14.8	13.1	13.1	15.8	12.6	15.0		14.6	15.0	10.7	
PO_4^{3-} (Phosphate nutrient)	3	1.1	1.1	0.9	1.3		0.9	1.2	0.2	0.7	0.5	1.0		1.0	1.2	0.9	
	6	4.9	3.2	3.9	3.2		1.6	2.1	0.9	1.2	1.3	1.6		1.3	2.2	0.8	

7.2 Improving soil aeration:

Based on the observed data from seven irrigation experiment stations in the Hunan, Jiangsu, Guangdong and Hubei provinces in southern China, the groundwater table in rice fields rose up to the soil surface and was maintained during the period of submergence under TRI, and it can be lowered to 0.3-0.8 m below the soil surface during the period of no submergence under WEI. The soil redox potential in rice fields under WEI is 120-200% of that under TRI [15]. This means that under WEI the soil oxygen content is increased greatly, the quantity of microorganisms can be increased, and poisonous compounds in the soil can be reduced.

According to the observed data from the Changsha Irrigation Experiment Station in Hunan Province (Table 14)[4], under WEI, the quantity of ammonifiers is 26 times greater than under TRI, while the number of organo-phosphorus bacteria is 6 times greater and the cellulose-decomposing bacteria is 10 times greater under WEI than under the TRI. The other important microorganisms in rice fields under WEI are also more abundant than under TRI.

Table 14. Number of microorganisms in early rice fields (unit: million/g of dry soil) at Changsha (1992)

Irrigation Technique	AWD		TRI	
Date of sampling	13 June	16 July	13 June	16 July
Aerobic bacteria	0.277	1.624	0.657	1.025
Anaerobic bacteria	0.021	0.015	0.035	0.017
Actinomycetes	0.422	0.288	0.161	0.094
Ammonifiers	11.550	112.000	0.355	4.200
Nitrifying bacteria	0.100	0.011	0.009	0.010
Denitrifying bacteria	0.390	0.400	0.085	0.042
Organo-phosphorus bacteria	4.025	0.960	0.710	0.420
Cellulose-decomposing bacteria	0.040	0.040	0	0.004
Sulphoficator	0.116	0.400	0.004	0.001
Desulphoficator	0.413	0.008	3.570	1.176

The condition of lower groundwater table, higher redox potential (higher soil oxygen content) and the greater number of microorganisms is very favorable for the transformation and assimilation of the organic fertilizer, and it is also very favorable for reducing the poisonous compounds in the soil. Therefore, the character of soil in rice fields can be improved and spreading WEI can increase the yield of rice.

7.3 Improving microclimatic condition of fields:

Based on statistics of the experimental results from seven irrigation experimental stations in four provinces in southern China, the microclimatic impacts of using WEI for rice are that the difference in air temperature at the row space of rice between day and night is increased by 1-5 , and the air relative humidity at the row space of rice was reduced by 1-5 percentiles [15]. Data from the Yulin Irrigation Experiment Station in the Guangxi Autonomous Region (Table 15) indicated that the condition of agricultural microclimate in rice fields under WEI was favorable not only for rice growing but also for reducing diseases, insect pests, and lodging of rice[24].

Table 15. Air temperature and relative humidity on rice fields at 2/3 of the height of rice at Yulin (1992)

Date of observation		6 June				9 June			
Weather types		Overcast				Clear			
O'clock of observation		8	14	20	Average	8	14	20	Average
Temperature	WEI	26.0	28.8	26.2	27.9	24.7	28.0	25.1	25.9
	TRI	26.1	27.2	26.1	26.5	24.0	26.8	25.0	25.3
Relative humidity	WEI	96	93	96	95	92	85	85	87
	TRI	96	96	96	96	96	89	84	90

7.4 Reducing rice diseases and insect pests:

The above-mentioned results of microclimatic impacts (the increase in air temperature difference between day and night and the decrease in air humidity) have shown that the field's microclimatic condition was favorable for reducing rice diseases and insect pests. Based on the observed data from the Yulin Agro meteorological Station, a comparison of the diseases and insect pests on rice for the two irrigation regimes is shown in Table 16 [27]. Values in Table 16 show that diseases and insect pests can be cut significantly under WEI. Thus, the quantity of pesticide used and the pesticide pollution in water, soil and rice can be reduced.

Table 16. Condition of the disease and insect pests for rice at Yulin (1990)

Variety of Rice	Early rice						Late rice		
Date of Investigation	1 June			28 June			15 September		
Name of Disease and Insect pests	Sheath and calm blight of rice			Rice plant hopper			Rice leaf roller borer		
Term	Total number	Number by disease	%	Total number	Number by disease	%	Total number	Number by disease	%
WEI	96	20	21	42	8	19	602	64	10.6
TRI	206	93	45	82	53	65	595	482	81
Remarks	Total number—Total number of investigated clumps of rice Number by disease—Number of clumps of rice by disease Number by insect pest—Number of clumps of rice by insect pest								

8. CONCLUSION:

(1) Three essential water efficient irrigation regimes (WEI) for rice, which include the regimes of combining shallow water depth with wetting and drying (SWD), alternate wetting and drying (AWD) and semi—dry cultivation (SDC), have been adopted in the different rice growing regions of China. (2) In comparison to the traditional irrigation regime—continuous deep flooding (TRI), rice yield can be increased slightly, water consumption and irrigation water use of paddy field can be decreased greatly and the water productivity of paddy field can be increased remarkably under the WEI. (3) The main causes of decrease of water consumption and irrigation water use are the decrease of the percolation rate in paddy field and increase in the utilization of rainfall. (4) A positive environmental impact is obtained by adopting WEI, the main cause of getting bumper yields were that the ecological environment under WEI is more favorable for the growth and development of rice than that under TRI, especially, the condition of soil aeration, which effects the growth and development of rice roots, is been improved. (5) For avoiding the decrease of yield under WEI, some measures, as timely

irrigation, coordinating irrigation with fertilization and weed control and maintaining an adequate water depth when meeting with the special weather, must be used. (6) Because of shortage of water resources in China is becoming more serious each year, the water efficient irrigation techniques should be further investigated and adopted on large areas.

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