IOP Conf. Series: Earth and Environmental Science **525** (2020) 012128 doi:10.1088/1755-1315/525/1/012128

Effects of Oxygation on Super Rice under Different Irrigation and Drainage Management Modes in Rice Field

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Abstract. The management mode of irrigation and drainage in field during the growth period of super rice will directly affect its growth trend, yield and water consumption. Increasing the oxygen content of irrigation water will help to promote the growth of rice and increase the yield. To understand the effect of oxygation on growth and yield of super rice, 7 irrigation and drainage management modes were designed and carried out in the super hydrid early rice field during the whole growth period by using oxygation and non-oxygation, so as to find a better management mode under different conditions. The results showed that the oxygation with the same irrigation in field had a significant effect on promoting the growth and increasing the yield of rice compared with that non-oxygation. However, the results of increasing the yield of rice by oxygation were very different among the modes. Under the oxygation condition, the Drought-tolerant II had the best growth trend and yield increase, and the irrigation water quantity was in the middle level, which had better water conservation and drainage reduction effect compared with the conventional mode. The Drought-tolerant II is "controlled irrigation and storage" mode, which is moderate water shortage controls irrigation and moderate rain storage controls drainage. The moderate water shortage controls irrigation mean that the soil moisture content is lower than 70% of the saturated water capacity as the irrigation control parameter during the drought in rice field. The moderate rain storage controls drainage the maximum rain storage depth of 200 mm as the field drainage control parameter during the rain in rice field. The results indicated that the Drought-tolerant II is a relatively optimal irrigation and drainage management method for rice field in southern China.

1. Introduction

Rice is the grain crop with the largest planting area in south China. Super hybrid rice is widely planted because of its advantages of drought resistance, insect resistance and high yield. Oxygation is a new irrigation technology that increases oxygen or dissolved oxygen in irrigation water. It can provide oxygen needed for root growth and development while supplementing crop water, and promote root growth, so as to increase crop production and income. Some research results showed that oxygation could promote the development of rice roots and the transformation of rhizosphere microorganisms [1-4]. Oxygation can also promote the growth of the abovementioned part of the crop, improve the water use and fertilizer use efficiency of the crop, and increase the crop yield [5-7]. Zhang et al. [8] found that the theoretical yield per plant of super rice was higher than that of non-oxygation rice by using different oxygation treatments. However, the results of experiments on oxygation only theoretically verified the significant effect of aerated irrigation on promoting rice growth and improving yield and quality under these laboratory conditions. Because of the high cost of oxygen-increasing equipment and the difficulty in solving the power problems in the field, there are few report on the experimental

IOP Conf. Series: Earth and Environmental Science **525** (2020) 012128 doi:10.1088/1755-1315/525/1/012128

research and practical application of oxygation in rice under field environment. The self-pressure inspiratory oxygen-increasing drainage pipe designed by Li et al. [9] broke this constraint and made oxygation in the rice field possible.

Different irrigation and drainage management mode in the field during the growth period of rice have great influence on its growth and yield. A good management mode of irrigation and drainage in the field can achieve the effects of water saving, emission reduction, quality improvement and yield increasing. Li et al. [10] put forward that the irrigation and drainage management mode of "controlled irrigation and storage" has been proved to be effective in saving water and reducing emissions. Its basic principle is as follow: Under the condition of fully grasping the water demand characteristics of rice, such as drought resistance and flood resistance, the drought resistance characteristic parameters of rice at each growth stage were used to moderately delay the irrigation time. During the dry period, irrigation was controlled to maintain low water layer or low water content in the field (when there was no water layer in the field), which caused a certain water stress to the growth of rice. While promoting the growth of rice, it could also reduce the loss of evapotranspiration in the field, increase the utilization rate of potential natural rainfall in the future, so as to reduce the irrigation water amount and achieve the effect of water saving and increasing yield. At the same time, by making full use of the flood-resistant characteristics of rice and the function of water storage in the paddy field, the natural rainfall can be stored in the paddy field to the maximum extent during the rainfall period, and the water displacement outside the paddy field can be reduced to achieve water saving and emission reduction. Therefore, the key of the mode is to fully grasp and utilize the drought and flood tolerance parameters of rice in each growth period.

At present, China is vigorously promoting the construction of high-standard farmland. As a method of efficient water-saving irrigation, pipeline irrigation has been listed as one of the main contents of high-standard farmland construction. On the basis of fully studying the water demand characteristics of rice such as drought resistance and flood resistance, the application of the oxygen-increasing irrigation technology and the "controlled irrigation and storage" mode to the management of irrigation and drainage in rice field will achieve the result of cost and efficiency saving. In this paper, the difference of physiological water demand characteristics of rice and the effect of water saving, emission reduction, quality improvement and efficiency improvement under different management modes of oxygation and non-oxygation were compared and studied by using self-pressure aspirated oxygen-increasing and oxygen-releasing water pipes and adopting the irrigation drainage mode of "controlled irrigation with central storage". The research results can provide basic data and scientific basis for the establishment of management system of water saving, emission reduction, quality improvement and efficiency improvement of rice under the condition of aerated irrigation in southern China.

2. Materials and Methods

2.1 Test site

There are 34 rectangular rice test plots in the central station of irrigation test, each of which is 15 m long and 9 m wide. Each test plot is divided by a concrete wall 1.8 meters deep and 0.35 meters thick to block the free exchange of water and fertilizer between adjacent plots and ensure the accuracy of test results. Each test field is equipped with an irrigation bleeder, an irrigation and drainage control valve, and an irrigation water metering meter, so that the test results can be applied in the field. The test site have the same climatic environment, water and fertilizer condition, irrigation and drainage management as the field, as well as complete field irrigation and drainage metering facilities, field water depth and soil moisture content measurement facilities.

2.2 Experimental design

The rice variety was selected as the early rice of Liangyou 189 super hybrid rice, which was carried out at the central station of irrigation test in Hunan province in 2018. Seedlings were transplanted on April 30 and harvested on August 5, and the growth period from transplanting to harvesting was 98d.

Two fields are provided for each drought-resistant and flood-resistant mode, one of which is equipped with a self-pressurized aspirated oxygen release pipe at the irrigation bleeder to form oxygen-enhancing irrigation. Two fields were set up in the conventional irrigation and drainage mode for comparison.

The field irrigation and drainage management mode of rice is mainly composed of irrigation control parameters, drainage control parameters and primary irrigation amount. During drought, the appropriate soil moisture content (depth of water layer) in each growing period of rice was used as the irrigation control parameter to judge whether the irrigation should be carried out. The appropriate irrigation control parameters and drainage control parameters are closely related to the drought and flood tolerance of rice in each growth period. The purpose of irrigation test is to find the "optimal critical value" of drought and flood tolerance of rice in each growth period. Rice growth stages can be divided into 8 stages from greenness to yellow ripeness, and each growth stage has an index of "optimal criticality" for irrigation and drainage, but there are an infinite number of possible test schemes. Based on the preliminary understanding of drought and flood tolerance of super rice, this study designed 3 modes of regulated deficit irrigation and drainage, namely, mild, moderate and severe, according to the degree of "water deficit" in the field that the rice could bear at each growth stage, which notes for Drought-tolerant I, II, III, respectively. The corresponding water depth of the field surface is denoted as -5mm, -10mm and -15mm respectively, indicating that the field surface has dried up, and the soil moisture content in the field is respectively 80%, 70% and 55% of the saturated water capacity. According to the rice flood tolerance, namely the maximum field water depth that can be retained during rainfall in rice paddies, we designed mild, moderate, severe 3 kind of water depth regulation, which notes for Flood-tolerant I, II, III, respectively. The maximum water depth of mild, moderate and severe is 250mm, 300mm and 350mm respectively. Each mode was compared with oxygation and non-oxygation irrigation systems. Among the three drought tolerance tests, moderate regulation and storage mode was adopted in case of rainfall. Comparing with the conventional irrigation and drainage management mode of "thin, shallow, wet and shai", which is widely used at present, the "controlled irrigation and storage" mode is actually a water-saving irrigation mode vigorously promoted in south China several years ago. In this study, relevant experiments were carried out on the management mode of irrigation and drainage in the 7 fields. Irrigation parameters of each test mode are shown as the following tables.

Table 1. Parameters of conventional irrigation and drainage mode of rice (control group)

Rice growth period	Green up stage			Early tillering phase			Late tillering phase			Field drying period		
	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax
Control parameter	10	20	100	10	30	100	0	30	150	-15	0	0
Rice growth period	Jointing-booting stage			heading and flowering period			Milky stage			Yellow ripening stage		
	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax
Control parameter	0	30	150	0	40	150	0	30	100	0	0	0

Table 2. Control parameters of drought-tolerant irrigation and drainage in rice

Rice growth period	Green up stage			Early tillering phase			Late tillering phase			Field drying period		
	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax
Drought-tolerant I	10	20	100	-5	30	150	-5	30	200	-15	0	0
Drought-	10	20	100	-10	30	150	-10	30	200	-15	0	0

tolerant II												
Drought-tolerant III	10	20	100	-15	30	150	-15	30	200	-15	0	0
Rice growth period	Jointing-booting stage			heading and flowering period			Milky stage			Yellow ripening stage		
	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax
Flood-tolerant mode I	-5	30	200	-5	30	200	-5	30	200	-5	0	0
Flood-tolerant mode II	-10	30	200	-10	30	200	-10	30	200	-10	0	0
Flood-tolerant mode III	-15	30	200	-15	30	200	-15	30	200	-15	0	0

Table 3. Control parameters of submergence resistant irrigation and drainage in rice

Rice growth period	Green up stage			Early tillering phase			Late tillering phase			Field drying period		
	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax
Drought-tolerant I	10	20	100	-5	30	150	-5	30	200	-15	0	0
Drought-tolerant II	10	20	100	-10	30	150	-10	30	200	-15	0	0
Drought-tolerant III	10	20	100	-15	30	150	-15	30	200	-15	0	0
Rice growth period	Jointing-booting stage			heading and flowering period			Milky stage			Yellow ripening stage		
	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax	hmin	h	hmax
Flood-tolerant mode I	-5	30	200	-5	30	200	-5	30	200	-5	0	0
Flood-tolerant mode II	-10	30	200	-10	30	200	-10	30	200	-10	0	0
Flood-tolerant mode III	-15	30	200	-15	30	200	-15	30	200	-15	0	0

Notes: in the table, hmin refers to the lower limit of suitable water layer on the field surface, namely the water depth under irrigation control (field soil moisture content), when the depth below this level, irrigation must begin; hmin=-5 indicates that the soil moisture content in the field is 80% of the saturated water holding rate, and the soil mud is not accounted for by barefoot tread in the field; hmin=-10 indicates that the soil moisture content in the field is 70% of the saturated water holding rate; hmin=-15 indicates that the soil moisture content is 55% of the saturated water holding rate and the field surface is generally open.

h refers to each irrigation to the field surface water layer deep.

hmax refers to the upper limit of field surface water layer (water-resistant depth).That is, above the depth of the water layer, the field began to drain.

The soil moisture in the field shall be determined by the instrument.

2.3 Test site

After transplanting rice seedlings, irrigation and drainage management of each experimental plot was carried out according to the 7 irrigation and drainage modes.

According to the irrigation test specification, the growth trend and irrigation quantity of rice in 14 test plots during the whole growth period were dynamically observed. The data on rice plant height, tillering and irrigation water at important time nodes of each growth period were observed and recorded respectively. Along the diagonal of the test field, 5 circles were marked as the observation base point according to the principle of equidistance. The plant height and tiller arithmetic mean measured from the observation base point were used as the observation values. Rice yield per field was measured by weighing method after rice harvest.

3. Results

3.1. Height of rice plant

The plant height values of super rice at each growth stage in different irrigation and drainage modes are shown in table 4 and figure 1. From May 13 to June 13, rice growth was in the period from the end of greening to the tillering stage, belonging to the physiological growth stage. After June 13, rice has completed the physiological growth and entered the reproductive growth stage. By July 15, the growth of plant height had almost stopped at the end of heading and flowering period. There were some differences but not significant in the characterization of plant height in rice growth trend of the 7 modes. Terminal plant height of Drought-tolerant II was slightly higher than the other six mode, and oxygation of Drought-tolerant II terminal plant height is highest, the value is 97.2 cm. Compared with the same irrigation and drainage mode, the height of the non-oxygenated irrigation plant was 1.2cm higher (96cm), and the Drought-tolerance III (93.2cm) with the lowest plant height was 4cm higher. Before June 13, however, Drought-tolerant II plant height was not showed obvious advantages, but between June 13 and July 15, the growth of plant height of this mode gradually accelerated, showing a comparative advantage with other modes. It was found that during this period, rice growth was in the period from Jointing-booting stage to heading and flowering period, which was the period of high growth of rice plants, the peak of physiological water demand, and the most sensitive period for rice to soil water. Drought-tolerant II belongs to the moderate control irrigation water shortage, namely when the field soil moisture content is less than 70% of saturated water capacity only for irrigation during the drought. This phenomenon shows that moderate water shortage have a role in promoting growth of rice plant height, Drought-tolerant II can better accorded with the rice water requirement characteristics. Drought-tolerant III and Flood-tolerant III average rice plant height value is lower than other irrigation and drainage mode. The results indicated that both excessive drought and deep submergence had great adverse effects on rice growth.

Table 4. Plant height of super rice at different growth stages by oxygation and non-oxygation (cm).

Irrigation and drainage mode	May 13	May 20	May 27	June 3	June 13	July 15
Conventional (non-oxygation)	44.2	57.1	62.4	75	89.4	95.1
Conventional (oxygation)	45.6	57.2	62.8	76.2	89.2	95.6
Drought-tolerant I (non-oxygation)	51.4	59.8	62.8	71	85.8	95.2
Drought-tolerant I (oxygation)	46.6	56.6	63.2	73	86.2	95.4
Drought-tolerant II (non-oxygation)	45.4	53.6	62.6	72	84.8	96
Drought-tolerant II (oxygation)	44.4	52.8	62.4	73.2	85.2	97.2
Drought-tolerant III (non-oxygation)	46.2	49.8	61.2	71.8	85.4	93.2
Drought-tolerant III (oxygation)	44.2	58.4	61.6	73	85.8	94.2
Flood-tolerant I (non-oxygation)	41.6	51	61.6	72.2	84.4	95.6
Flood-tolerant I (oxygation)	42.4	54.8	61.8	73.6	85.2	95.6
Flood-tolerant II (non-oxygation)	44.6	56.4	62.8	74	89.2	95.6
Flood-tolerant II (oxygation)	44.4	56.4	62.6	74.4	89	95.8
Flood-tolerant III (non-oxygation)	41.2	43.2	60.4	72	85.4	93.4
Flood-tolerant III (oxygation)	41.4	43.2	60	72.2	85	93.6

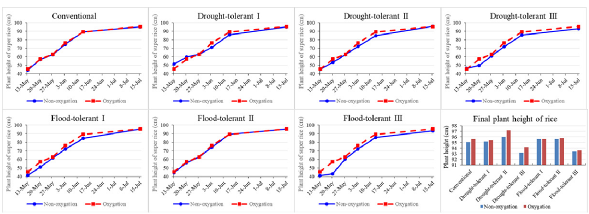

Fig. 1. Plant height of super rice was irrigated with oxygen and without oxygen under 7 irrigation and drainage modes.

3.2. Tillering of rice plant

Tiller Numbers of super rice at each growth stage in different irrigation and drainage modes are shown in table 5 and figure 2. Rice tillering basically began on May 13 at the end of the greenization period, and ended on June 13 at the end of field drying period, and the effective tillering terminated. At this time, the measured average panicle number per bag is the effective tillering number. The results showed that: 1. In the early tillering period (before May 20), there was no significant difference in tillering number among the 7 modes, and no significant difference was found between the oxygation and non-oxygation. However, from the late tillering period to the end of field drying period (the control of ineffective tillering), the tillering differences of the 7 modes increased and the trend changed significantly, and the difference between oxygation and non-oxygation of each irrigation mode also showed up. 2. The effective tillering numbers of oxygation were higher than that of the no-oxygation in the 7 modes. 3. The number of effective tillering in Drought-tolerant II was the highest, followed by conventional mode. 4. The effective tillering number of Drought-tolerant III and Flood-tolerant III was the least. Combined with the data of plant height in table 4, it was found that the growth trend of rice in these two irrigation and drainage modes was not as good as that in other modes, which indicated that excessive drought and deep submergence were not conducive to rice tillering.

Table 5. Tillering mean records of super rice at different growth stages by oxygation and non-oxygation (Tree/pocket).

Irrigation and drainage mode	May 13	May 20	May 27	June 3	June 13
Conventional (non-oxygation)	4.69	7.14	9.38	10.85	11.25
Conventional (oxygation)	4.76	7.56	9.8	11.06	11.48
Drought-tolerant I (non-oxygation)	4.48	6.86	9.24	10.92	11.46
Drought-tolerant I (oxygation)	4.48	7	9.38	11.34	11.48
Drought-tolerant II (non-oxygation)	4.48	6.58	9.52	10.64	12.52
Drought-tolerant II (oxygation)	4.34	6.44	9.1	10.64	12.96
Drought-tolerant III (non-oxygation)	4.34	6.72	9.66	10.22	10.88
Drought-tolerant III (oxygation)	4.62	6.72	9.38	10.36	10.92
Flood-tolerant I (non-oxygation)	4.62	6.72	10.08	10.5	11.16
Flood-tolerant I (oxygation)	4.64	6.72	10.4	10.64	11.4
Flood-tolerant II (non-oxygation)	4.76	7.14	9.94	11.06	11.46
Flood-tolerant II (oxygation)	4.9	7.14	10.08	11.06	11.48
Flood-tolerant III (non-oxygation)	4.48	6.58	8.68	9.94	10.64
Flood-tolerant III (oxygation)	4.34	6.44	9.24	10.08	10.78

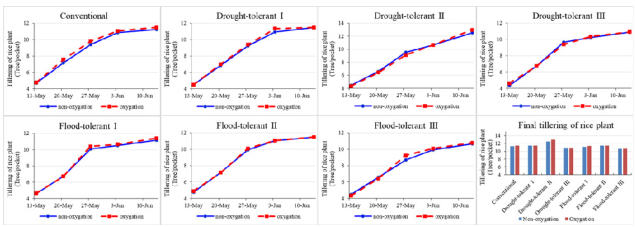

Fig. 2. Tillering number of super rice was irrigated with oxygen and without oxygen under 7 irrigation and drainage modes.

3.3. Rice yield

The yield difference of super rice under 7 irrigation and drainage modes was obvious (table 6, figure 3). The yield of 7 modes has the following characteristics: 1. Oxygation yield were higher than the same irrigation mode of non-oxygation, which can increase 2.7% to 6.3%. Among them, the yield difference between oxygation and non-oxygation of Drought-tolerant II was the highest, the yield of oxygation was 24.7kg higher than non-oxygation, with an increase of 6.3%. Under the conventional mode, oxygation can increase the yield by 6% than non-oxygation. The yield difference between oxygation and non-oxygation of Flood-tolerant III was the lowest, the yield of oxygation was 10.3kg higher than non-oxygation, with an increase of 2.7%. 2. Compared with oxygation and non-oxygation, the range of yield increase is closely related to the irrigation and drainage mode. Combined with data of table 7, it showed that the irrigation mode with more irrigation times and more irrigation water (such as conventional irrigation and drainage), as well as the comprehensive effect of water saving and production increasing better irrigation and drainage modes (such as Drought-tolerant I, II, and Flood-tolerant I) has better effect on the implementation of oxygation.

Table 6. Yield of super rice by oxygation and non-oxygation.

Irrigation and drainage mode	Conventional	Drought-tolerant I	Drought-tolerant II	Drought-tolerant III	Flood-tolerant I	Flood-tolerant II	Flood-tolerant III
Oxygation	413.5	414.6	419.4	398.0	412.8	415.3	396.0
Non-oxygation	390.1	393.0	394.7	387.5	397.2	400.5	385.7
Units increased in production	23.4	21.6	24.7	10.5	15.6	14.8	10.3

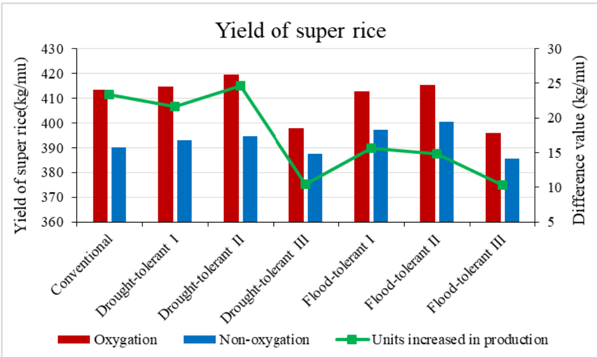

Fig. 3. Yield of super rice irrigated with and without oxygen under 7 irrigation and drainage modes.

3.4. Rice irrigation water amount

The results of the irrigation water amount of rice in 7 modes showed that the irrigation times and irrigation water amount varied greatly (table 7, figure 4). The conventional mode irrigated 9 times during the whole growth period, the average water consumption was 175 m^3/ mu, which was significantly higher than other modes. Drought-tolerant I was irrigated 7 times in the whole growth period, and the total average water consumption was 135 m^3/ mu. Drought-tolerant II and Flood-tolerant I were irrigated 6 times in the whole growth period, and the average irrigation water was 115 m^3/ mu. Drought-tolerant III and Flood-tolerant II were irrigated 5 times in the whole growth period, and the average irrigation water was 94 m^3/ mu. Flood-tolerant III were irrigated 4 times, which was the least in the whole growth period, and the average irrigation water was 74 m^3/ mu. The mode considered the drought tolerance of rice and delayed irrigation, also used the rice field ridge to store the natural rainfall to the maximum extent, so that the irrigation times and the irrigation amount were reduced during the rice growth period. Compared with the conventional mode, the irrigation water for 5 times was reduced by 101 m^3/ mu. From the perspective of water saving, the Flood-tolerant III is the most water saving mode. In this experiment, there was no difference in irrigation amount between oxygation and non-oxygation.

Table 7. The irrigation water amount of rice for 7 irrigation and drainage modes by oxygation and non- oxygation.

Irrigation and drainage mode	Average Irrigation (m^3/mu)
Conventional (non-oxygation)	175
Conventional (oxygation)	175
Drought-tolerant I (non-oxygation)	135
Drought-tolerant I (oxygation)	135
Drought-tolerant II (non-oxygation)	115
Drought-tolerant II (oxygation)	114
Drought-tolerant III (non-oxygation)	94
Drought-tolerant III (oxygation)	94
Flood-tolerant I (non-oxygation)	115
Flood-tolerant I (oxygation)	115
Flood-tolerant II (non-oxygation)	94
Flood-tolerant II (oxygation)	94
Flood-tolerant III (non-oxygation)	74
Flood-tolerant III (oxygation)	74

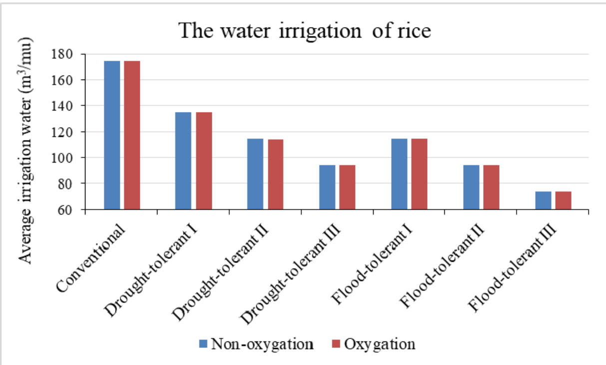

Fig. 4. The oxygation and non-oxygation water amount of 7 irrigation and drainage modes.

4. Conclusion and discussion

(1) The irrigation and drainage management mode in the rice growing period had significant effects on its growth, yield and irrigation amount. With the same climatic conditions and agronomic measures, different irrigation and drainage management modes will have different effects on water saving and yield increasing. The results show that it is important to strengthen the research and application of advanced irrigation and drainage management technology in rice field.

(2) The average plant height, tiller number and yield of rice in Drought-tolerant II were higher than other irrigation and drainage modes, and the yield increased significantly. The irrigation amount was in the middle of the upper level. Compared with the current conventional irrigation and drainage mode, the Drought-tolerant II had better water-saving and emission reduction effects. The mode coupled well the goals of water saving and yield increasing. It means that the soil moisture content is lower than 70% of the saturated water capacity as the irrigation control parameter during the drought in rice field, and the maximum rain storage depth of 200 mm as the field drainage control parameter during the rain in rice field, which also can be called the mode of "controlled irrigation and storage". Compared with the other 6 irrigation and drainage modes, either the yield increase effect is better but the irrigation amount is too high, such as the conventional irrigation and drainage mode, or the water-saving effect is outstanding but the rice yield is not high, such as Drought-tolerant III and Flood-tolerant III. Therefore, the accurately grasping the drought and flood tolerance characteristics of rice in its growth

period, and properly "regulating deficit" and "regulating storage" irrigation and drainage can receive the effect of water saving and emission reducing, and improve the quality and increase production.

(3) The oxygation with different irrigation and drainage modes can obviously promote the growth and yield of rice under field conditions. However, the results of oxygation with different irrigation and drainage modes were quite different. The irrigation and drainage mode with more irrigation times and irrigation amounts (e.g. conventional mode) and with better comprehensive effect of saving water and increasing yield (such as Drought-tolerant I, II, and Flood-tolerant I) have better effect of implementing oxygen increasing irrigation.

(4) There is an optimal critical parameter of irrigation and drainage control in each growth period of rice, which is related to the characteristics of water demand of rice and the coupling matching degree of the function of rain storage of rice field and the distribution of natural rainfall. The irrigation test is the most effective way to find the optimal irrigation and drainage management mode. However, due to the limitation of conditions, the conclusion of one irrigation experiment is biased, and the conclusion of this paper needs to be verified by further experiments.

(5) Many laboratory experiments have shown that oxygation of rice can significantly save water and increase yield. However, in this field oxygation test, it was not found that oxygation has obvious water-saving effect, which may be related to the test accuracy.

Acknowledgement
The present study was financially supported by the Water Conservancy Science and Technology Project of Hunan Province (XSKJ2018179-45, XSKJ2018179-34, and XSKJ2018179-31). Special thanks to the Test Center of Irrigation and Research Center for Water Resources assistance in the field. We thank all participants in sample collection and data analysis.

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