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Full Length Article

Effects of Drought-Flood Abrupt Alternation on Yield and Physiological Characteristics of Rice

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Abstract

Drought-flood abrupt alternation is a frequent meteorological disaster that occurs during summer and sometime in autumn in southern China and the Yangtze river basin. In the present study, super hybrid rice (*Oryza sativa* L.) was used to assess the effects of drought-flood abrupt alternation on yield components in pot experiments. At the tillering stage, four treatments were provided, no droughts and no floods (control), droughts but no floods (duration of droughts 8 d), no droughts but floods (duration of floods 8 d), and drought-flood abrupt alteration (duration of droughts 8 d and floods 8 d). Yield components and physiological characteristics, such as chlorophyll content, endogenous hormones, osmotic adjustment substances and photosynthetic parameters were measured. The yield per plant of 2014 year declined in the droughts, floods, and drought-flood abrupt alteration treatments by 29.5, 11.4, and 37.7%, respectively, lower than that in control, it suggests that droughts was more disadvantageous than floods, and a synergistic decline in yield under drought-flood abrupt alteration. Compared to the control, drought-flood abrupt alteration significantly reduced the effective panicles per plant, number of grains per panicle, primary and secondary branches, and seed-setting rate. Additionally, chlorophyll content and net photosynthetic rate was reduced to some extent under droughts, floods, and drought-flood abrupt alteration. Particularly, chloroplasts were degraded under drought-flood abrupt alteration, and the net photosynthetic rate significantly declined during the initial stage. Transpiration rate, stomatal conductance, and intercellular CO_2 concentration in the reciprocal second leaf showed relatively large fluctuations in the different treatments. At the initial stage after treatment, the free proline and malondialdehyde content increased greatly and kept high for longer time under drought-flood abrupt alteration. Compared to the control, endogenous auxin content of drought-flood abrupt alteration was lower, whereas the abscisic acid content was higher during the initial stage. Decrease of photosynthesis capacity as well as imbalance of endogenous hormones may be the cause of yield significantly reduction for drought-flood abrupt alteration. © 2018 Friends Science Publishers

Keywords: Super hybrid late rice; Net photosynthetic rate; Plant hormones; Tillering stage; Yield components

Introduction

Droughts and floods are major meteorological disasters that have large effects on human life and safety, and threaten agricultural production (Dong *et al.*, 2011). Rice plants come into being the adaptive faculty to environmental changes during the long-term acclimation process, such as changes in water availability. However, up to date most parts of China encounter droughts, which cause 20–30% decrease in production annually. At the same time, floods in spring, floods in succession in spring and summer in the Yangtze river basin, floods in succession in summer and autumn in southern China occur frequently, such as Jiangxi, Hunan, Anhui, and Guangdong province of China, etc., which usually reduce rice yield greatly. Meteorological research showed that droughts and floods have been more serious over the past 30 years in Jiangxi and other southern regions, with an overall increasing trend (Cai *et al.*, 2013). In particular, droughts followed by floods over a large area significantly reduces rice yield, which was called “drought-flood abrupt alternation”. Drought-flood abrupt alternation is a meteorological disaster that occurs in southern China, particularly in the Yangtze river basin during summer. During this season, alternating droughts and floods result in the coexistence of extreme events and reactions over a short period (Wu *et al.*, 2007). According to statistics from previous studies, in 14 years between 1960 and 2012, drought-flood abrupt alternation occurred in China. Once every 4 years, and a total of 23 extreme climate conditions of drought-flood abrupt alternation occurred at the Huaihe River (Wang *et al.*, 2014). In 2011, 42 counties (cities or districts), nearly three million people and a crop area of 9.04 million hm^2 were affected by this event, which led to 5.8 billion Yuan economic losses in Jiangxi province.

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Especially in the Huaibei plain area, many serious "drought-flood abrupt alternation" natural disasters occurred (Shen *et al.*, 2012), it was found that compared with the control treatment, the yield of drought-flood abrupt alternation treatment was reduced by 30.3%, and it was the most unfavorable to the yield, through the analysis on yield reduced law of rice under the conditions of drought-flood abrupt alternation (Gao *et al.*, 2017).

To date, there have been some studies on problems associated with the cultivation, physiology, ecology, genetics, breeding, and other aspects of damage to rice caused by droughts (Jaleel *et al.*, 2013; Kumar *et al.*, 2014; Lauteri *et al.*, 2014) and floods (Magneschi and Perata, 2008; Zulkarnain *et al.*, 2009; Habib *et al.*, 2016; Yan *et al.*, 2017). At the molecular level, it has been found that both severe droughts and floods adversely affect the growth and development of rice and cause reductions in yield of crops (Couée *et al.*, 2006; Kawano *et al.*, 2008; Singh *et al.*, 2017). A great deal of discussion on the problem of re-watering after droughts has led to the conclusion that significant growth compensation will occur after moderate droughts (Zhou *et al.*, 2011; Chen *et al.*, 2013). However, little attention has been paid to drought-flood abrupt alternation effects on the yield and physiology of rice. Few studies have considered the effects of irrigation and water conservation on drought-flood abrupt alternation in rice (Suralta and Yamauchi, 2008; Xiangping *et al.*, 2013; Zhen *et al.*, 2015; Hongfei *et al.*, 2017). Previous studies on the effects of drought-flood abrupt alternation on rice have several deficiencies in the study methods. First, the physiological and biochemical indices used for the assessments are not efficient. More specifically, the changes in endogenous hormones have not been examined in depth, although changes in endogenous hormones content of rice leaves at different growth stages can reflect the strength of its resistance to droughts or floods to a certain extent. Therefore, a detailed study on the effects of drought-flood abrupt alteration induced endogenous hormones changes on physiological mechanisms is necessary. Secondly, because of the different material, experimental and analytical methods, droughts and floods occurrence periods, and intensity and duration of various levels used in the previous studies, the results were different. Xiangping *et al.* (2013) reviewed the research progress of the alternate droughts and floods stress, and pointed out that the superposition effect under droughts and floods alternate stress may be synergistic effect or antagonistic effect. Therefore, droughts-flood abrupt alternation will result in what kind of effect is not very clear. Additionally, double-cropping rice in the Yangtze river basin of China has played an key role in agriculture in recent years, and frequent droughts and floods, particularly drought-flood abrupt alternations, have severely affected rice production (Peng *et al.*, 2009). With the recent cultivation of many double-cropping super hybrid rice varieties, we know relatively little about their water stress resistance and physiological responses after droughts, floods, and drought-flood abrupt alternation.

Hence, the present study used a double-cropping super hybrid late rice variety as the testing material. It was released recently to increase the rice production area in Jiangxi province of China. The treatments simulating meteorological disasters were no droughts and no floods (NDNF), droughts but no floods (DNF), no droughts but floods (NDF), and drought-flood abrupt alteration (DFAA) at the tillering stage. Variations among the treatments were determined based on yield components, chlorophyll content in the reciprocal second leaf, photosynthetic parameters, osmotic adjustment substances and endogenous hormones (ABA, IAA, GA_3, and ZR). The relationship between yield and physiological indices was assessed. The findings might provide a reference for the mitigation of meteorological disasters under conditions resembling the drought-flood abrupt alteration treatment.

Materials and Methods

Experimental Details and Treatments

Experimental material: Wufengyou T025 was a dominant double-cropping super hybrid late rice (*Oryza sativa* L.) variety, which was planted in the Jiangxi province, located in the region where double-cropping rice is carried out in southern China (Wufeng A/Changhui T025, a super rice variety certified by China's Ministry of Agriculture in 2010). As a double-cropping late rice variety, its yield was recently revealed to be superior at several places in Jiangxi. Its entire growth period is around 112.3 days.

Cultivation methods: The experiment was carried out at the science and technology park of Jiangxi agricultural university (28°46′N, 115°50′E, altitude: 48.8 m, annual average temperature: 17.5°C, average annual sunshine: 1720.8 h, annual average evaporation: 1139 mm, and average annual rainfall: 1747 mm), Nanchang, Jiangxi province, China, in 2013 and 2014. The results were consistent over the two years. Therefore, we have major reported the results of the study conducted in 2014. Rice was planted in plastic buckets (height: 24.0 cm, the inner diameter of the upper portion: 29.0 cm, and the inner diameter at the bottom: 23.5 cm). Soil samples were taken from the upper soil layer (0–20 cm) in the rice experiment field at the science and technology park of Jiangxi agricultural university. The physical and chemical properties of the experimental soil were in Table 1. The soil was naturally air-dried, pulverized using a soil disintegrator (FT-1000A, Changzhou WIK Instrument Manufacturing Co. Ltd. China), and sieved through a 100-mm mesh. Each pot contained approximately 10 kg dry soil, which was soaked in water two weeks prior to transplantation, and 5 g compound fertilizer (N-P-K=15%-15%-15%) was applied to each treatment. After re-watering, 3 g of a compound fertilizer was applied, and properly growing seedlings were transplanted (three per bucket). The seeds were sown on June 23, and the seedlings were transplanted on July 23. All the cultural practices for pest and disease control and other management practices were performed.

Treatments: Through the analysis of the historical data of drought-flood abrupt alteration events (Cheng *et al.,* 2012), it was found that the drought-flood abrupt alteration often occurred at early August in the Yangtze river basin. At this time, the double-cropping late rice of the Yangtze River basin was at tillering stage. Therefore, the rice drought-flood abrupt alteration stage was set at the tillering stage in this experiment. The start and end dates of droughts and floods were set to emulate natural droughts and floods disasters experienced by double-cropping rice in the Yangtze river basin. For droughts treatment, remaining water in plastic buckets were drained and moved to the rain shelter before raining. Soil moisture content was monitored by vacuum meter type soil moisture meter (measuring range 0 ~ 85 kPa, Institute of Chinese Academy of Sciences), and the rice was naturally droughts. The soil water potential after droughts treatment for 6 d exceeded the maximum measured value of the instrument, and droughts treatment continued for 2 d until the soil was white and cracking, and the plants were wilting and withered (severe droughts). For floods treatment, plants in soil-containing pots were completely submerged in a high square box (Height: 100 cm) filled with water in a greenhouse, the water used in the experiment were static, clean tap water and not exchanged the water during submergence period. For drought-flood abrupt alteration treatment, after the droughts treatment immediately began to floods treatment, whereas the plants subjected to the control treatment was maintained in a 3~5 cm water layer. Four treatments, each treatment of three replicates were applied, and 15 pots were constituted each replication, using a randomized block design (Table 2).

Determination of Indices

Chlorophyll content: First day after treatment (August 23, the peak tillering stage), every four days (seven times), five reciprocal second leaves (it referred to the first fully expanded leaves from the topside counting at present) of rice per replicate with good, consistent growth were selected for chlorophyll content measurements. Chlorophyll content was measured from the base, middle, and top of each leaf using a SPAD-502 chlorophyll analyzer (Zhejiang Tuopu Instrument Co. Ltd., China), and the average chlorophyll content was calculated.

Indices of photosynthetic parameters: On August 29, cloudless weather was set from 9:30 to 12:00 h. Five reciprocal second leaves of rice per replicate with good, consistent growth, were selected. Net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Cs), and intercellular CO_2 concentration (Ci) were measured six times on the central leaf using a CI-340 portable photosynthesis analyzer (CID Bio-Science, USA).

Determination of free proline and malondialdehyde content: First day after treatment, the reciprocal second leaf was frozen in liquid nitrogen, transferred to a refrigerator, and preserved at -80°C, the sample was called 0.5 g when it was determined, The content of free proline was measured by reference to Li (2000) and nin-hydrin, the absorbance was measured under 520 nm in spectrophotometer, MDA (malondialdehyde) content was determined by reference to Li (2000) thiobarbituric acid (TBA) methods, the absorbance values were measured under 450 nm, 532 nm and 600 nm in spectrophotometer. The content of malondialdehyde was calculated by the following formula: $C = 6.45 \times (A532 - A600) - 0.56 \times A450$

$$\text{MDA molar concentration}/(\mu\text{mol}\cdot\text{g}^{-1}) = C \times N \times W^{-1}$$

The C was MDA concentration ($\text{umol}\cdot\text{L}^{-1}$), N was the volume of extract (L), and W was the fresh weight of the sample (g).

Endogenous hormones: First day after treatment, the reciprocal second leaf was frozen in liquid nitrogen, transferred to a refrigerator and preserved at -80°C, after which abscisic acid (ABA), trans-zeatin-riboside (ZR), auxin (IAA), and gibberellin A_3 (GA_3) were measured using an enzyme-linked immunosorbent assay (ELISA) (Golovatskaya and Karnachuk, 2007).

Yield components: Ten plants without damage were selected per replication and harvested after maturity (October 23). Panicle length, filled grains per panicle, empty grains per panicle, 1000-grain weight, the number of primary and secondary branches, effective panicles per plant, and yield and biomass per bag were determined. Total grain number per panicle, seed-setting rate, and harvest index were also calculated.

Statistical Analysis

DPS 9.5 and Origin 8.5 were used for analysis and mapping of the data.

Results

Yield and its Components

The yield of super hybrid late rice decreased to different extents under the different water stress treatments (Table 3). Yield per plant of 2014 year decreased by 29.5, 11.4 and 37.7% in DNF, NDF, and DFAA treatment, respectively, compared with the treatment of NDNF. There were significant ($P<0.05$) differences between the DFAA, DNF and NDNF treatment. However, the differences between DNF and DFAA, and NDF and NDNF were not significant, while the yield of DFAA was 11.64% lower than that of DNF. This suggested that droughts had more severe effects on super hybrid late rice yield than floods, drought-flood abrupt alternation created a synergistic effect for the reduction of yield.

Table 1: Physical and chemical properties of the experimental soil

Soil pH	Organic matter (mg kg^{-1})	Total nitrogen (g kg^{-1})	Available nutrient (mg kg^{-1})		
			N (nitrogen)	P (phosphorus)	K (potassium)
5.6	34.7	2.3	85.3	29.3	98.6

Table 2: Water treatments for super hybrid late rice Wufengyou T025

Treatments	Duration of droughts (d)	Start and end dates (month. day)	Duration of floods (d)	Start and end dates (month. day)
NDNF	0		0	
DNF	8	August 7–August 14	0	
NDF	0		8	August 15–August 22
DFAA	8	August 7–August 14	8	August 15–August 22

NDNF: no drought and no floods; DNF: drought but no floods; NDF: no drought but floods; DFAA: drought-flood abrupt alteration

Table 3: Yield and its components under different water treatments during the year 2013 and 2014

Year	Treatments	Yield per plant (g)	Effective panicles per plant	Total grains per panicle	Seed-setting rate (%)	1000-grain weight (g)	Number of primary branches	Number of secondary branches	Panicle length (cm)	Harvest index (%)
2014	NDNF	38.0±2.2a	9.0±0.6a	234.4±6.8a	96.4±0.2a	20.1±0.2a	12.0±0.2a	42.4±1.3a	23.1±0.5a	53.0±2.0a
	DNF	26.8±1.1b	7.5±0.3bc	217.0±7.1ab	88.5±1.2b	19.7±0.3a	10.8±0.2b	39.5±1.3ab	22.7±0.7a	54.8±1.3a
	NDF	33.7±2.6a	8.0±0.5ab	233.4±5.3ab	88.8±1.3b	20.1±0.2a	12.4±0.2a	41.8±1.3a	22.8±0.3a	48.5±2.2a
	DFAA	23.7±1.2b	6.5±0.4c	214.0±6.2b	91.7±1.3b	19.7±0.3a	10.6±0.1b	37.8±1.3b	22.2±0.3a	49.5±2.3a
2013	NDNF	21.7±1.4a	7.3±0.3a	214.2±6.1a	87.9±5.0a	20.6±0.5a	11.1±0.2a	34.4±2.6a	25.0±0.5ab	
	DNF	16.3±0.2ab	5.3±0.6a	208.0±16.7a	82.8±2.6a	20.24±0.2a	11.20±0.3a	37.2±1.6a	25.5±0.2ab	
	NDF	20.3±2.5ab	6.3±0.9a	207.6±10.0a	86.3±4.1a	19.72±0.3a	11.5±0.2a	37.57±1.9a	24.7±0.7b	
	DFAA	15.2±3.5b	5.0±1.0a	203.8±19.1a	82.6±4.0a	20.12±0.4a	11.1±0.2a	37.8±1.5a	25.0±0.4ab	

Mean ± standard deviation. Values with same letter differ non-significantly (P<0.05). NDNF: no drought and no floods; DNF: drought but no floods; NDF: no drought but floods; DFAA: drought-flood abrupt alteration

The drought-flood abrupt alternation treatment had negative effects on yield at the tillering stage.

Among the yield components of 2014 year (Table 3), effective panicles per plant and total grains per panicle revealed patterns of variation similar to that of yield per plant, with the best and worst performances observed under NDNF and DFAA, respectively. These traits were significantly (P<0.05) lower under DNF than under NDF. Non-significant difference was noted in 1000-grain weight among all the treatments. The seed-setting rate in the DNF, NDF, and DFAA treatments was significantly lower than that in NDNF. Among the different water treatments, the seed-setting rate of DNF was the lowest. The number of primary and secondary branches was lower under DNF, NDF, and DFAA than that under NDNF, and the number of primary and secondary branches was the lowest in DFAA. Significant (P<0.05) differences in grains per panicle were observed between DFAA and NDNF. However, non-significant difference in panicle length and harvest index was found among the different water treatments. The panicle length was the lowest under DFAA and harvest index was the lowest under NDF. Thus, spike formation in the super hybrid late rice was affected under DFAA and DNF, resulting in yield reduction at the tillering stage. And the main reason was that effective panicles per plant and the total grains per panicle significantly decreased (P<0.05).

From the data of 2013 and 2014 year (Table 3), the trends for changes in different treatments were basically consistent for different years, especially drought-flood abrupt alternation of yield per plant significantly decreased (P<0.05).

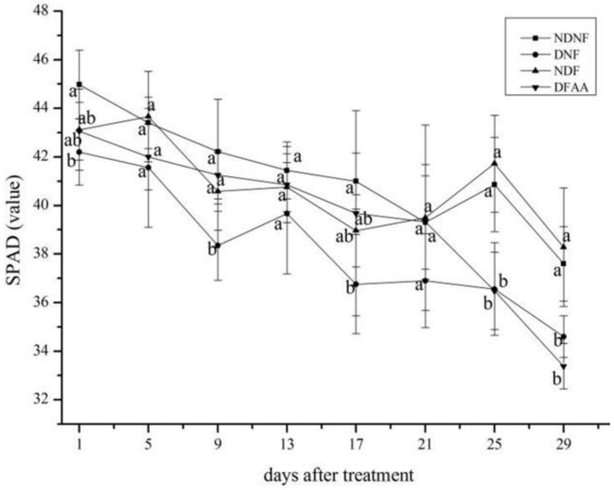

Fig. 1: Dynamics of SPAD values in the reciprocal second leaf among treatments during the year 2014.The data in figure is average and the short lines represents the mean square deviation and different letters in the same days indicate that the means are statistically different (P<0.05). NDNF: no drought and no floods; DNF: drought but no floods; NDF: no drought but floods; DFAA: drought-flood abrupt alteration

Chlorophyll Content and Photosynthetic Indices

The chlorophyll content of rice in reciprocal second leaf showed a decreasing trend along with growth advance after treatment (Fig. 1). Chlorophyll content was relatively lower under DNF, NDF, and DFAA than that under NDNF, DNF was the lowest and NDNF was the highest at the initial stage after treatment, and the gap was further amplified with plant growth and developmental. At first day after treatment, the chlorophyll content between NDNF and DNF treatment was significant difference ($P<0.05$). At twenty-fifth day after treatment, the chlorophyll content of NDF was the highest. At twenty-ninth day after treatment, the chlorophyll content of DFAA was the lowest, and significant difference ($P<0.05$) with NDNF and NDF. This result showed that a certain level of drought-flood abrupt alternation and droughts could accelerate chlorophyll degradation and promote the aging process in rice, and effects of drought-flood abrupt alternation on rice growth and development were more serious at the later stage after treatment.

Overall, Pn was the highest under NDNF and the lowest under DNF in the reciprocal second leaf (Fig. 2A). At first day after treatment, the Pn of DNF was the lowest and the Pn of NDNF was the highest, but there was no significant difference between the two treatments. At seventeenth day after treatment, the Pn of DNF was the lowest and the Pn of NDNF was the highest, and the difference was significant ($P<0.05$). Pn was slightly higher under NDF than under DFAA at the initial stage after treatment, but it declined under DFAA during plant growth and development. At twenty-fifth day after treatment, Pn was at higher under DFAA. At thirtieth day after treatment, the Pn of NDNF was still the highest, and the Pn of DNF was still the lowest. Whereas the lowest Tr levels were observed under DNF. At thirtieth day after treatment, Tr was the lowest in DNF, followed by the lower in DFAA, and DNF, DFAA were significantly different ($P<0.05$) from NDNF (Fig. 2B). The amplitude of fluctuation mean was the larger and the average value was the lower for Cs under DNF and under DFAA with the development of the fertility process (Fig. 2C). In addition, the Ci under DNF fluctuated significantly. Tr, Cs and Ci under NDNF were the most stable and fewer fluctuations (Fig. 2D). It was suggested that droughts is seriously detrimental to photosynthetic capacity of rice leaf.

Free Proline and MDA Content

The free proline content of DNF, NDF and DFAA increased rapidly from first day to fifth day after treatment (Fig. 3A), at fifth day after treatment, 46.90, 36.13 and 14.29% were higher than that of NDNF, respectively and significant difference was found in DNF, NDF and NDNF ($P<0.05$), the free proline content of DFAA was the highest at eighth day after treatment, but at later stage after treatment the free proline content of DNF, NDF and DFAA decreased slowly, at sixteenth day after treatment, the free proline content of NDNF was the highest, and the free proline content of DFAA was the smallest, and the difference between the two treatments was significant ($P<0.05$).

At the initial stage after treatment, MDA content of DNF, NDF and DFAA increased rapidly (Fig. 3B), compared with other treatments, MDA content of DFAA was the highest from first day to twelfth day after treatment, and at fifth day after treatment, MDA content of NDF reached the maximum value, 82.33, 63.93 and 56.06% higher than those of NDNF, DNF and DFAA respectively, and the difference was significant ($P<0.05$), then MDA content of DFAA began to decrease, but that of DFAA was higher than the NDNF at sixteenth day after treatment.

Endogenous Hormones

Leaf IAA increased rapidly under DFAA during the initial stage after treatment (Fig. 4A). From first day to fifth day after treatment, IAA increased by 40.5, 25.7 and 16.3% under DFAA, NDNF and NDF, respectively in the reciprocal second leaf. During the growth of the plants, leaf IAA levels increased in the NDF and DFAA treatments, but decreased significantly under DNF, suggesting that droughts stress might accelerate IAA degradation in the leaves of super hybrid late rice, and re-watering after floods might slow down IAA degradation somewhat.

GA_3 levels in leaf showed an initial increasing trend, followed by a decrease (Fig. 4B). From first day to fifth day after treatment, leaf GA_3 under NDF, DFAA and NDNF increased by 69.1, 7.5 and 4.9%, respectively. With the development and growth, GA_3 content in the reciprocal second leaf under NDNF and DNF was slightly greater than that in NDF and DFAA. In addition, the fluctuations in GA_3 content were significantly lower in NDNF and DNF than in NDF and DFAA.

Leaf ZR was the lowest under DFAA, and it revealed an increasing trend, followed by decrease (Fig. 4C). From first day to fifth day after treatment, ZR of the reciprocal second leaf under DFAA, NDNF, DNF, and NDF increased by 63.3, 14.0, 4.7 and 11.6%, respectively. During plant growth and development, leaf ZR fluctuation was significantly higher under DFAA than under the other treatments, and it was most stable under NDNF.

For a long-period, leaf ABA content and its rate of decline were the highest under DFAA, whereas from first day to fifth day after treatment, leaf ABA content under DNF and NDF increased significantly by 17.8% and 68.0%, respectively (Fig. 4D). At seventeenth day after treatment, leaf ABA content was the lowest under NDNF, whereas it was higher under NDF and DFAA, indicating that these treatments, particularly NDF, could promote leaf ABA accumulation to enhance cell aging.

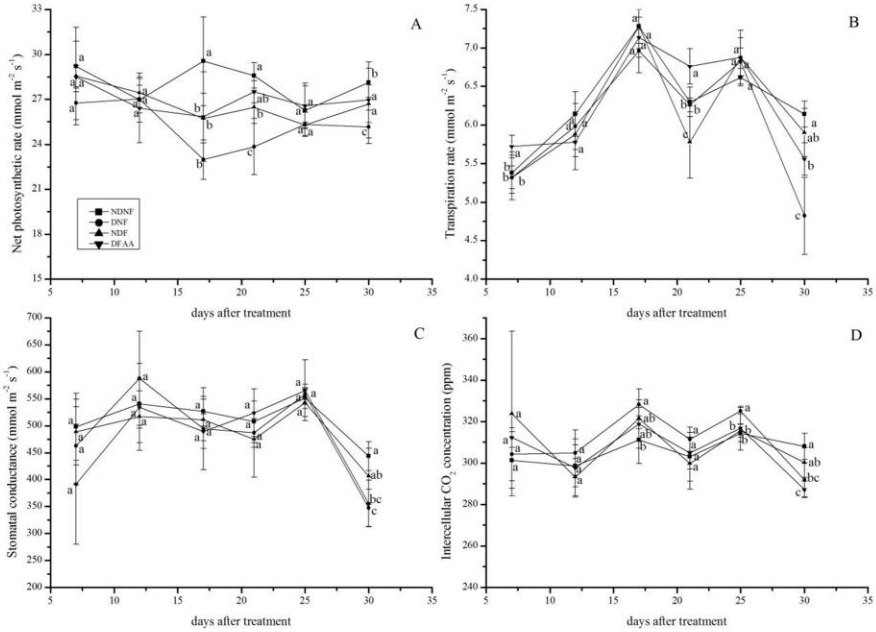

Fig. 2: Dynamics of photosynthesis indices in the reciprocal second leaf among treatments during the year 2014. The data in figure is average and the short lines represents the mean square deviation and different letters in the same days indicate that the means are statistically different ($P<0.05$). NDNF: no drought and no floods; DNF: drought but no floods; NDF: no drought but floods; DFAA: drought-flood abrupt alteration

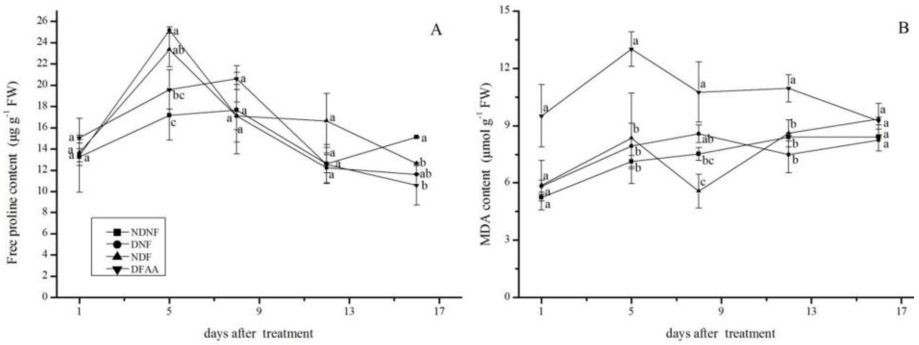

Fig. 3: Dynamics of free proline content (A) and MDA (malonaldehyde) contents (B) in the reciprocal second leaf among treatments during the year 2014. The data in figure is average and the short lines represents the mean square deviation and different letters in the same days indicate that the means are statistically different ($P<0.05$). NDNF: no drought and no floods; DNF: drought but no floods; NDF: no drought but floods; DFAA: drought-flood abrupt alteration

Discussion

When rice plants were subjected to varying degrees of water stress (droughts or floods), the yield components varied to a certain extent. Chen *et al.* (1993) found that droughts stress caused reduction in the number of panicles per rice plant, ultimately leading to reduction in yield. Wang *et al.* (2013) reported that water stress stimulated root growth in rice, thereby preventing ineffective tiller development and increasing yield, which was consistent with the findings of Chen *et al.* (1993). In the present study, yield under DNF was significantly lower than that under NDNF at the tillering stage, consistent with the findings of Ding *et al.* (2002). In another study, submergence stress caused a decrease in the number of effective panicles per plant and total grains per panicle, then the rice yield was decreased, and the rate of empty shell production was higher when exposed to extended flooding time, whereas 1000-grain weight was lower (Zhang *et al.*, 2014; Zhou *et al.*, 2014a). Li and Li (2000) indicated that submergence stress caused reduction in the number of effective panicles per plant, the number of filled grains, 1000-grain weight, and seed-setting rate to varying extents, and the most crucial factor, causing decline in yield, was the reduction in seed-setting rate.

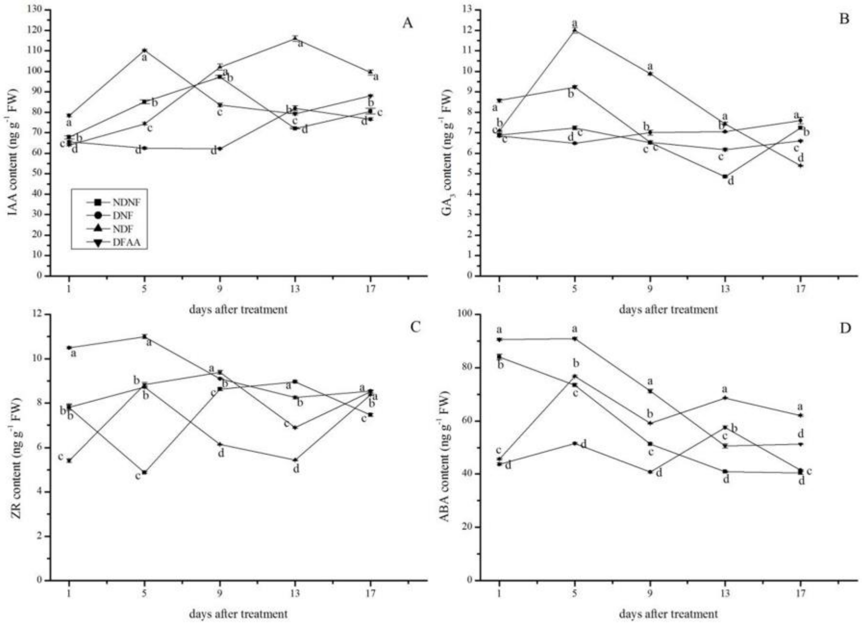

Fig. 4: Dynamics of endogenous hormones (auxin, IAA; gibberellin A_3, GA_3; trans-zeatin-riboside, ZR; abscisic acid, ABA) content in the reciprocal second leaf among treatments during the year 2014. The data in figure is average and the short lines represents the mean square deviation and the different letters in the same days indicate that the means are statistically different ($P<0.05$). NDNF: no drought and no floods; DNF: drought but no floods; NDF: no drought but floods; DFAA: drought-flood abrupt alteration

The present study showed that, NDF caused reductions in effective panicles per plant and seed-setting rate by 11.1% and 7.9%, respectively lower than that in NDNF during the tillering stage. Xiangping *et al.* (2013) reported that alternate droughts and floods might have synergistic or antagonistic effects. In the present study, the yield per plant in 2014 under DFAA, DNF, NDF, and NDNF varied significantly ($P<0.05$), and it was 25.7% higher under NDF than under DNF, the results suggested that droughts affected the yield of rice at the tillering stage more than floods did, the effects of the droughts treatment are probably related to the severity of the droughts (in this study, the DFAA meteorological disasters were artificially maintained at severe droughts) and the rapid growth of plants after floods stress, considering that leaf tips were no longer submerged at second day, and that rapid internode elongation and leaf respiration could somewhat alleviate the effect of submergence on yield reduction. In this study, the yield per plant was the lowest under DFAA. Cai *et al.* (2008) indicated that rice root activity increased under droughts stress, which can alleviate the adverse effects of submergence stress during the later stage. Although the root activity increased under droughts stress, the adverse effects of later floods stress could be alleviated. But in order to imitate drought-flood abrupt alteration disaster in Yangtze river basin, the rice plants leaf tip was very serious damaged after droughts treatment, and nearly one third of leaves where withered and died, so physiological mechanisms such as photosynthesis of rice plants have been destroyed. However, rice plants alternate from droughts to floods stress immediately caused rice yield significantly decreased. It indicated that drought-flood abrupt alteration on rice at the tillering stage was antagonistic effect. The results of the present study showed that even under severe droughts, floods, and drought-flood abrupt alteration, a lower yield of rice was not obtained at the tillering stage, which is a water sensitive stage, but the decline in rice production was inevitable. Therefore, when such meteorological disasters occur during production, we should not abandon the harvest. Droughts alleviating measures, such as hydrating young seedlings, should be actively taken when actual production is hit by droughts. To alleviate the effects of the floods disasters, timely drainage and necessary disaster management measures should be adopted.

Chlorophyll content and carotenoid levels decrease under droughts and floods stresses. Lu *et al*. (1999) showed that the chloroplast ultrastructure was damaged under droughts stress, and that the chloroplast was degraded, thereby reducing its content. Moreover, Li and Li (2000) showed that submergence stress caused a decline in chlorophyll content, and with prolonged submergence times, this effect increased. However, Xiangping*et al*. (2006) reported that the physiological characteristics of maize leaves are affected by re-watering after droughts stress. The chlorophyll content over a certain period was higher after re-watering than in the control treatment. In the present study, we found that at the end of the treatments, within

30 d following the SPAD measurements, chlorophyll content was lower under DNF, NDF and DFAA than under NDNF, suggesting that these three treatments, especially DFAA, could accelerate chloroplast degradation, thereby leading to reductions in chlorophyll content. Furthermore, carotenoid content was reduced, and leaf senescence was promoted. In addition, SPAD was slightly increased At twenty-fifth day after treatment under "floods" treatments, which may be related to the lack of droughts stress, and the subsequent application of fertilizer to make the leaves green.

Water stress affects the physiological and biochemical functions of leaves. The study showed that the photosynthetic rate, the stomatal conductance and the intercellular CO_2 concentration at the tillering stage were significantly reduced (Lu *et al.*, 2016). Previous studies (Wu *et al.,* 2014) have reported that the Pn and Cs are significantly reduced under droughts stresses, and the photosynthetic products are obstructed. Li and Li (2000) showed that rice was damaged after floods, Pn was decreased, and this decreasing trend continued for longer periods when submergence was increased. Yuan *et al.* (2008) showed that Pn, Tr and Cs of leaves increased after mild submergence and gradually reached higher levels than that in the control. When severe submergence was decreased during the later stages, their levels gradually became lower than those in the control. In the present study, Pn was decreased under DNF, NDF, and DFAA, and it was the lowest under DNF. This suggests that photosynthesis was affected by droughts. An insufficient supply of photosynthates made it difficult for the secondary tiller to form effective panicles, and grain filling at the later stage and seed-setting rate were reduced. Pn was the highest under DFAA At twenty-fifth day after treatment. DFAA had certain compensatory effects on photosynthetic rate and its related parameters, which might be the reason why seed-setting rate was higher under this treatment than under DNF or NDF. Tr, Cs, and Ci showed high and low fluctuations at the end of the treatments, which might have been caused by the differences in the development of the rice plants. Under water stress, plants are actively accumulated in various organic or inorganic substances to improve the concentration of cell fluid, reduced osmotic potential, and increased cell uptake or water retention capacity (González *et al.*, 2008). Duan *et al.* (2014) showed that proline content and MDA content increased in different degrees at young panicle differentiation stage, and the difference reached a very significant level ($P<0.01$). This study results showed that at the initial stage after treatment, the content of free proline and MDA accumulated rapidly during young panicle differentiation, which was basically consistent with the results of Duan *et al.* (2014). At the initial stage after treatment, MDA content of DFAA increased greatly, while at the later stage after treatment, the content of MDA in DFAA was still high. The results showed that DFAA treatment damaged rice leaves more and recovered more slowly after treatment.

Several studies (Chen *et al.*, 2013; Hisano *et al.*, 2016; Verbon and Liberman, 2016) have proven that the effect of endogenous hormones on the regulation of plant growth and development is often the result of the combined effects of various hormones, and that osmotic stress in plants causes the accumulation of large amounts of ABA. Ajialatie *et al.* (2014) showed that a decline in endogenous hormones at the tillering stage directly affects crop yield, and that a lower IAA or higher ZR level is beneficial for tillering. Zhou *et al.* (2014b) reported that the synthesis of a large amount of ABA was induced and cytokinin (CTK) synthesis was inhibited under droughts stress. The results of the present study showed that endogenous ABA was significantly lower under DNF and NDF than under NDNF at the initial stage after the treatment, but gradually increased later. However, endogenous ABA levels were always higher under DFAA than under NDNF. This effect might be because the rice plants, after the removal of the droughts and floods stresses compensated for the negative effects by decreasing ABA production to recover growth rapidly. DFAA promoted ABA accumulation to prevent short-term damage, but it was difficult to reduce the damage quickly under NDNF. This might have caused rice plants to be unable to produce new tillers, which delayed tillering, thereby inhibiting young panicle growth. Finally, the effective panicles per plant and total grains per panicle were decreased, which resulted in the decrease in yield, which was consistent with our results of yield components.

Overall, there was rapid degradation of chlorophyll, significantly decrease of net photosynthetic rate, imbalance of growth-promoting hormones and growth-inhibitory hormones at the initial stage after treatment, whether droughts or floods, especially drought-flood abrupt alternation, we can find the reasons from the pathway of genes, proteins or metabolism, so as to understand the molecular mechanism of drought-flood abrupt alternation for yield reduction and provides a theoretical basis for the disaster prevention and mitigation, which needs to be explored further.

Rice planted in pots could not get the ground water supplement like the field environment after droughts, resulting in the slightly higher temperature in pots than in field. Meanwhile, floods in the field will bring about the accumulation of sediment on the rice leaves, whereas tap water was used for this experiment, which may be a flaw in this experiment.

Conclusion

Droughts, floods, drought-flood abrupt alternation caused a decrease in the yield of super hybrid late rice at the tillering stage and drought-flood abrupt alternation created a synergistic effect for the reduction of yield. The main reason for the decrease in yield under drought-flood abrupt alternation at the tillering stage may be the reductions in effective panicles per plant and number of grains per panicle. This may be related to accelerated degradation of chlorophyll in rice leaves, significantly decreased photosynthetic rate, greatly increased of osmotic adjustment substances of free proline and MDA content and this situation can last for a long time, and the imbalanced ratio of endogenous growth promoting hormones to inhibited hormones after treatment.

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