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CHANGES AND RELATIONSHIP OF CLIMATE AND LATE-RICE YIELD IN CHENZHOU CITY OF SOUTH HUNAN PROVINCE OF CHINA

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Abstract

The changes and relationship of climate parameters and late-rice yield per unit area during the growth periods of late-rice from 2010 to 2019 were quantitatively analyzed in order to provide scientific guidance for countermeasures against climate change and sustainable production of late-rice. The climate parameters include cumulative daily sunshine hours (S), mean daily temperature (T), cumulative daily precipitation (P), mean daily relative humidity (H), daily highest and lowest temperatures (T_h and T_l), days of high temperatures ($D_{T \geq 30°C}$ and $D_{Th \geq 35°C}$) and low temperature ($D_{Tl < 15°C}$). Results showed that: (i) Late-rice yield was significantly increased quadratically from 5621.33 kg hm^2 in 2010 to 6333.65 kg hm^2 in 2019 with a mean of 5959.2 kg hm^2. (ii) According to the suitable climate conditions for growth of late-rice, T and P were low but H was suitable in the whole field growth period of late-rice, T was suitable in the transplanting-tillering stage, but was low in the booting-heading and milk ripening-mature stage. $D_{T \geq 30°C}$, $D_{Th \geq 35°C}$ and $D_{Tl < 15°C}$ was meanly 7.7, 7.5 and 6.4 d, respectively, which showed possible occurrence of the damages to late-rice due to high and low temperatures. iii) Only T, T_h and T_l in the booting-heading stage showed significant positive correlation with year, and the optimal regression models were in quadratic and exponential types. The climate parameters of S, T and T_h in the boot-heading stage were significantly positively correlated with late-rice yield, and the optimal regression models were all in quadratic types. Daily highest temperature (T_h) affected late-rice yield most (61.04%), followed by T (36.50%), and S affected least (2.46%). Considering the current conflict in the field planting periods between tobacco and late-rice, late rice varieties needs to be bred with short growth period and high tolerance to both high and low temperatures.

Introduction

As the world's largest rice producer, the rice-planting area in China accounts for about 19% of the rice-planting area in the world), and rice yield of China could affect the food security of China and even the world. China is the sensitive and significant impact country of global climate change, the warming trend in China is similar to that in the world. It is well known that climate change can affect the growth of rice, yield and quality (Ai *et al*. 2014, Shen 2015, Wang and Yang 2020, Yang *et al*. 2013,Tao *et al*. 2013). The middle and lower reaches of the Yangtze River are the main rice-planting regions in China, There are some studies which reported the general trend of climate changes in recent years in this region (Mei and Yang 2005, Su *et al*. 2006, Ma *et al*. 2012, Zhang and Lou 2013).

Suitable climate conditions for rice growth are generally as follows (Practical Rice Cultivation 1981): daily sunshine hours ≥8 hrs, cumulative precipitation 700~1200 mm, relative humidity 70~80%; mean daily temperature ≥15~17℃, 25~30℃ and 23~28℃ in the transplanting-tillering, booting-heading and milk ripeness-maturing stages, respectively.

Chenzhou City is located in the south of Hunan Province and about 80% of the farmlands are the paddy fields. However, the trend of climate change in recent years and its effect on late-rice

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yield per unit area are still not clear in Chenzhou. Therefore, in the present study, Guiyang County, with the largest rotation area of tobacco and late-rice in Chenzhou, was elected as the study area, the changes and the relationship of late-rice yield per unit area and climate parameters during late-rice growth period from 2010 to 2019 were quantitatively analyzed in order to provide scientific guidance for countermeasures against climate change and sustainable production of late-rice.

Materials and Methods

Data of late-rice yield per unit area is from the Statistical Yearbook of Guiyang County from 2010 to 2019. Data of climate parameters from January 1 of 2010 to December 31 of 2019 were obtained from the National Meteorological Station in Guiyang County (Station No.: 57973, located at 112°43'29"E and 25°44'58"N with the altitude of 329.1 m), eight climate parameters were used in this study, including cumulative daily sunshine hours (S), mean daily temperature (T), cumulative precipitation (P), mean daily relative humidity (H), daily highest and lowest temperatures (Th and Tl), days of high temperatures (DT ≥ 30°C and DTh ≥ 35°C) and low temperature (DTl < 15°C).

The total field growth period of late-rice in Guiyang County is generally from August 1 to November 10, in which the transplanting-tillering stage is from August 1 to 31, the booting-heading stage from September 1 and October 10, and the milk ripening-mature stage from October 11 to November 10.

Microsoft Excel 2016 and IBM Statistics SPSS 22.0 software were used for statistical analysis, regression analysis and plotting of the data.

Results and Discussion

During the period of 2010~2019, The late-rice yield per unit area is ranged from 5621.3 to 6333.7 kg hm^2 with a mean of 5959.2 ± 233.2 kg hm^2, and the coefficient of variation was 3.91%, a low degree of variation. The skewness was 0.22, a positive skewness distribution. The kurtosis was -0.79, a form of plat peak. Figure 1 showed that the mean late-rice yield per unit area (y) exhibited a quadratic increase trend with year (x), and the regression model was as follow: y = 2.2285 x 2-8903.1 x +9 × 10^6, R^2 = 0.969, $p < 0.01$, RMSE = 47.07.

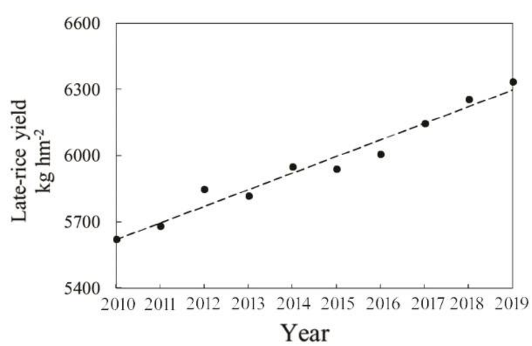

Fig. 1. Change of late-rice yield per unit area from 2010 to 2019.

The statistical information of climate parameters presented in Table 1 showed that: (i) S, P and H during the whole field growth period of late-rice were 5.2 hrs, 302.7 mm and 71.1%, respectively. Sunshine hours and P were low but H was appropriate for late rice planting (Practical Rice Cultivation 1981). Mean daily temperature was 26.6~29.4, 21.8~26.0, and 16.5~19.4°C, with a mean of 28, 24.1, and 17.9℃ in the transplant-tillering, booting-heading, and milk ripening-mature stages, respectively. Mean daily temperature was suitable in the transplanting-tillering stage, but low in the booting-heading and milk ripening-mature stages for late rice planting (Practical Rice Cultivation 1981). $D_{T \geq 30℃}$ and $D_{Th \geq 35℃}$ were meanly 7.7 and 7.5 d, respectively in the booting-mature stage, and $D_{T < 15℃}$ was meanly 6.4 d in the milk ripening-mature stage, indicating the possible occurrence of the damages due to high and low temperatures to late rice.

Table 1. Statistics of climatic parameters in Guiyang County from 2010 to 2019.

Parameter	Growth stage	Min	Max	Mean	Sd	Cv	Skewness	Kurtosis
S	Whole period	462.0	644.8	530.3	56.3	10.62	0.67	0.50
	Stage 1	151.1	257.9	211.1	30.2	14.32	-0.58	0.59
	Stage 2	141.7	280.7	195.2	42.5	21.77	0.85	0.53
	Stage 3	57.6	174.9	124.0	35.4	28.52	-0.67	0.29
P	Whole period	154.7	467.1	303.7	105.9	34.85	-0.03	-1.06
	Stage 1	60.6	334.4	163.8	98.8	60.30	1.10	-0.23
	Stage 2	3.5	162.5	65.5	51.0	77.91	0.84	0.06
	Stage 3	11.9	115.6	74.4	36.5	49.01	-0.85	-0.37
H	Whole period	66.5	78.4	71.1	4.4	6.13	0.79	-0.89
	Stage 1	60.7	83.0	69.8	6.3	9.08	0.86	1.05
	Stage 2	58.9	76.1	70.7	5.4	7.65	-1.18	1.37
	Stage 3	65.3	87.2	73.0	7.1	9.78	0.79	0.00
T	Whole period	22.4	24.5	23.4	0.7	2.80	0.32	-0.62
	Stage 1	26.6	29.4	28.0	1.0	3.46	0.09	-1.48
	Stage 2	21.8	26.0	24.1	1.4	5.64	-0.09	-0.61
	Stage 3	16.5	19.4	17.9	1.1	5.91	0.27	-1.42
T_h	Whole period	26.4	29.4	27.7	0.9	3.09	0.72	0.78
	Stage 1	31.0	34.3	32.5	1.2	3.73	0.07	-1.25
	Stage 2	25.7	31.2	28.3	1.7	6.09	0.46	-0.58
	Stage 3	20.5	24.0	22.0	1.4	6.53	0.25	-2.07
T_l	Whole period	19.5	21.1	20.4	0.5	2.55	-0.22	-0.89
	Stage 1	23.7	25.7	24.8	0.7	2.78	-0.24	-1.23
	Stage 2	19.3	22.8	21.1	1.1	5.14	-0.34	-0.28
	Stage 3	13.3	16.4	14.9	0.9	6.25	-0.11	-0.36
$D_{t \geq 30℃}$	Whole period	2.0	18.0	8.4	5.9	69.69	0.42	-1.11
	Stage 1	1.0	15.0	7.7	5.9	76.97	0.03	-2.04
	Stage 2	0	4.0	1.6	1.9	118.59	0.48	-2.04
	Stage 3	0	0	0	0	/	/	/
$D_{th \geq 35℃}$	Whole period	0	28.0	9.5	8.8	92.20	1.21	0.94
	Stage 1	0	18.0	7.5	6.7	88.72	0.53	-1.16
	Stage 2	0	11.0	1.9	3.5	183.08	2.38	6.03
	Stage 3	0	0	0	0	/	/	/
$D_{t<15℃}$	Whole period	4.0	14.0	7.7	2.8	36.76	1.15	1.97
	Stage 1	0	0	0	0	/	/	/
	Stage 2	0	7.0	1.3	2.5	195.44	1.87	2.28
	Stage 3	0.0	10.0	6.4	3.1	47.85	-1.05	0.83

S, cumulative daily sunshine hours (h); P, cumulative daily precipitation (mm); H, mean daily relative humidity (%); T, mean daily temperature (℃); T_h, daily highest temperature (℃); T_l, daily lowest temperature (℃); $D_{T \geq 30℃}$, days with T ≥30℃; $D_{T \geq 35℃}$, days with T_h ≥35℃; $D_{T<15℃}$, day with T <15℃. Whole period, whole field growth period of late-rice; Stage 1, transplant-tillering stage; Stage 2, booting-heading stage; Stage 3, milk ripeness-mature stage.

(ii) During the whole field growth period of late-rice, the variation coefficients of S and P were 10.62~28.52 and 34.85~77.91%, respectively, both showing moderate variation. The variation coefficients of H, T, T_h and T_l were 6.13~9.78, 2.80~5.91, 3.09~6.53 and 2.55~6.25%, respectively, all showing low degree variation. The variation coefficients of $D_{T\geq 30°C}$, $D_{Th\geq 35°C}$ and $D_{T<15°C}$ were 73.29~118.59, 88.72~183.08 and 36.76~195.44%, respectively, all showing moderate to high variation. The skewness of T_h, $T_{\geq 30°C}$ and $D_{Th\geq 35°C}$ were 0.07~0.72, 0.03~0.48 and 0.53~2.38, respectively, all showing positive skewness distribution; The skewness of T_l was -0.11~-0.34, showing a negative skewness distribution; The skewness of other climate parameters had positive and negative values in different growth stages, showing positive or negative skewness distribution. The kurtosis of $D_{Th\geq 35°C}$ was 6.03 in the booting-heading stage, showing the form of steep-peak (kurtosis > 3), but the kurtoses of other climate parameters ranged from 0 to 2.28, showing the form of flat peak.

Table 2 showed that the Pearson correlation coefficients between climate parameters with year. Only significant positive correlations were found between T, T_h, and T_l with year ($P < 0.05$) in the boot-heading stage, the optimal regression models were both in quadratic types between T and T_h with year, while in exponential type between T_l with year (Table 3, Fig.2).

Table 2. Correlation between climatic parameters with year.

Growth stage	Correlation	S	P	H	T	T_h	T_l	$D_{t\geq 30°C}$	$D_{th\geq 35°C}$	$D_{t<15°C}$
Whole period	Pearson correlation	0.187	0.009	0.370	0.563	0.580	0.563	-0.288	0.115	-0.253
	Sig. (2-tailed)	*0.605*	*0.981*	*0.293*	*0.090*	*0.079*	*0.090*	*0.419*	*0.751*	*0.481*
Transplant-tillering stage	Pearson correlation	-0.406	0.077	0.577	0.127	0.121	0.188	-0.102	-0.097	/
	Sig. (2-tailed)	0.244	0.833	0.081	0.727	0.739	0.602	0.779	0.791	/
Booting-heading stage	Pearson correlation	0.578	-0.319	-0.281	0.718*	0.756*	0.641*	0.309	0.459	-0.527
	Sig. (2-tailed)	*0.080*	*0.368*	*0.432*	*0.019*	*0.011*	*0.046*	*0.384*	*0.182*	*0.117*
Milk ripening-mature stage	Pearson correlation	-0.050	0.265	0.504	-0.141	-0.139	-0.093	/	/	0.204
	Sig. (2-tailed)	*0.890*	*0.460*	*0.137*	*0.698*	*0.701*	*0.799*	/	/	*0.572*

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Optimal regression models between climatic parameters with year (x) at booting-heading stage.

Climatic parameter	Optimal regression model	R^2	Rsme	P
T	$Y = 0.0222x^2 - 89.301x + 89646$	0.535*	1.00	0.019
T_h	$Y = 0.0429x^2 - 172.37x + 173214$	0.603*	1.20	0.011
T_l	$Y = 4\times10^{-9}e^{0.0111x}$	0.407*	0.04	0.046

Table 4 showed the Pearson correlation coefficients between climate parameters with yield per unit area of late-rice. It can be seen that S, T and T_h in the boot-heading stage were significantly positively correlated with late-rice yield per unit area, among of which, S and T were significantly correlated with late-rice yield per unit area at the level of $P < 0.05$, and T_h was significantly correlated with late-rice yield per unit area at the level of $P < 0.01$. The optimal regression equations were all in quadratic types (Table 5, Fig. 3).

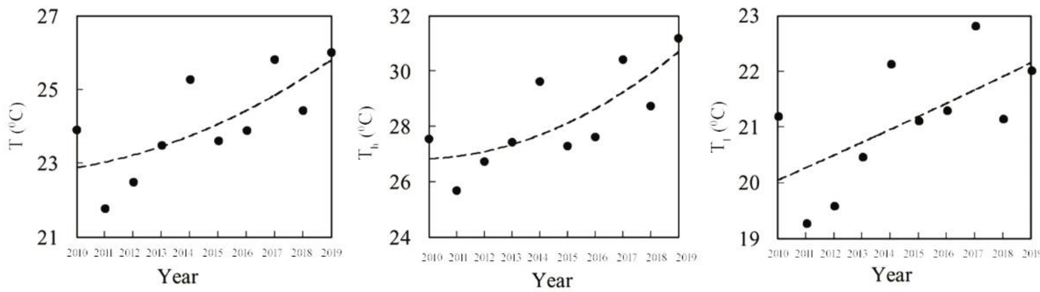

Fig. 2. Correlation between climatic parameters with year at booting-heading stage.

Table 4. Correlation between climatic parameters with late-rice yield per unit area.

Growth stage	Correlation	S	P	H	T	T_h	T_l	$D_{t\geqslant30}$	$D_{th\geqslant35}$	$D_{t<15}$
Whole growth stage	Pearson correlation	0.279	-0.016	0.304	0.563	0.611	0.503	-0.312	0.122	-0.295
	Sig. (2-tailed)	0.435	0.966	0.393	0.090	0.061	0.139	0.380	0.738	0.408
Transplant-tillering stage	Pearson correlation	0-.429	0.112	0.610	0.113	0.106	0.157	-0.125	-0.113	/
	Sig. (2-tailed)	0.216	0.758	0.061	0.756	0.771	0.665	0.730	0.755	/
Booting-heading stage	Pearson correlation	0.658*	-0.436	-0.390	0.730*	0.793**	0.616	0.372	0.517	-0.434
	Sig. (2-tailed)	0.038	0.207	0.265	0.017	0.006	0.058	0.290	0.126	0.210
Milk ripening-mature stage	Pearson correlation	0.020	0.262	0.450	-0.149	-0.116	-0.134	/	/	0.088
	Sig. (2-tailed)	0.956	0.465	0.191	0.682	0.750	0.712	/	/	0.809

*. **Correlation is significant at the 0.05 or 0.01 level (2-tailed).

Table 5. Optimal regression equation between climatic parameters with year (x) at booting-heading stage.

Climatic parameter	Optimal regression model	R^2	Rsme
S	$Y = 3.6124x + 5254.1$	0.434	186.13
T	$Y = 13.596x^2 - 528.09x + 10769$ $r^2 = 0.5488$	0.549	178.61
T_h	$Y = 106.78x + 2941.8$	0.624	150.67

IBM Statistics SPSS 20.0 was used to obtain the standardized coefficients of S, T and T_h in the multiple linear regression model with late-rice yield per unit area in the booting and heading stage, and the percentage of the coefficient of each climate parameter in sum of the standardized coefficients of the three climate parameters was calculated to stand for the impact degree or contribution rate of climate parameter on late-rice yield per unit area (Sun *et al.* 2009, Wang *et al.* 2020) (Table 6). It could be seen that the effect of T_h was the highest on late-rice yield, which was 61.04%, followed by T, which was 36.50%, while the influence of S was the least, which was only 2.46%.

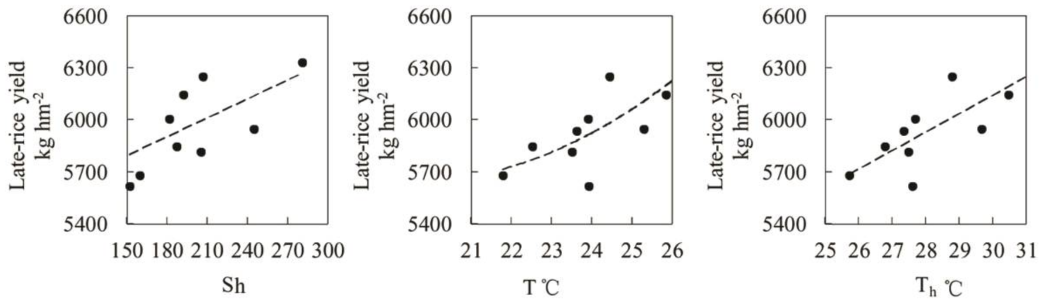

Fig. 3. Correlation between climatic parameters with late-rice yield per unit area at booting-heading stage.

Table 6. Impact degrees of climate parameters on late-rice yield per unit area at booting-heading stage.

Climatic parameter	S	T	T_h	In total
Impact degree %	2.46	36.5	61.04	100

Previous studies reported that the general change trend of climate in the middle and lower reaches of the Yangtze River were as follows: temperature increased (Zhang and Lou 2013, Zhang *et al*. 2020), precipitation decreased, extreme precipitation increased (Mei and Yang 2005, Su *et al.* 2006), and sunshine hours decreased (Ma *et al.* 2012). However, it was found through this study that there were some differences in climate changes with the previous studies during late-rice growth period in Guiyang County, for examples, in the present study, only the temperature (mean daily temperature, daily highest and lowest temperatures) at late-rice transplant-tillering stage significantly increased with year. Sunshine hours generally showed an insignificant increase trend with year in the whole growth period of late-rice, in the transplant-tillering and boot-heading stages, but an insignificant decrease trend in the milk ripening-mature stage (Table 1). Generally, precipitation increased insignificantly with year during the whole growth period of late-rice, in the transplant-tillering and milk ripening to mature stages, but decreased insignificantly in the boot-heading stage (Table 1). The temperature (mean daily temperature, daily highest and lowest temperature) in the whole growth period, the transplant-tillering and the boot-heading stages of late-rice showed the insignificant increase trend with year, but showed the insignificant decrease trend with year in the milk ripening-mature stage (Table 1). The main reason for the above differences might be that the previous studies mostly focused on the climate conditions of double-cropping rice (the field growth period is usually from April to November), but the present study concerned the climate conditions of late-rice rotated with tobacco (the field growth period is usually from August to November), which caused the differences in the climate conditions between the previous studies with the present study. In addition, it also showed that the relationship between climate parameters and rice yield obtained in the previous studies could not be directly applied to Guiyang County, and the climatic conditions during late-rice planting period must be considered.

The present study showed that the yield per unit area of late-rice in Guiyang generally increased with year during 2010~2019, which is consistent with the increase trend year by year of the mean rice yield per unit area in China (Zhang *et al*. 2008), but the current highest yield per unit area of late-rice in Guiyang is only about 80% of the expected yield per unit area in China (7500 kg hm^2) (China's rice yield per unit area is expected to achieve a third leap 2000), showing a great increase potential for late-rice yield per unit area.

It is further revealed that for the normal growth of late-rice, cumulative sunshine hours and precipitation are low but mean relative humidity was appropriate in Guiyang during the whole growth period of late-rice, and mean temperature was suitable in the transplanting-tillering stage, but low in the booting-heading and milk ripening-mature stages. It possibly occur for the damage to late-rice due to high and low temperatures (Practical Rice Cultivation 1981), so effective measures should be found and adopted to avoid or reduce the negative influences of climate changes on late-rice planting in Guiyang.

Previous studies (Chen *et al*. 2017, Liu 2018, Su *et al*. 2020) reported that the impact of temperature rise on the yield per unit area of late-rice were different in the different regions in the middle and lower reaches of the Yangtze River, which was increased in Hunan (Liu 2018). The present study further showed that sunshine hour, mean daily temperature and daily highest temperature in the booting-heading stage presented significant positive correlation with the yield per unit area of late-rice suggesting that the increase of sunshine hours and temperature, to a certain extent, could lead to the increase in late-rice yield per unit area. Cao *et al*. (2012) also found that sunshine hours were significantly positively correlated with the yield per unit area of late-rice, which was consistent with the present study.

Rice yield could be affected by many factors, including climate factors, cultivation and management factors, and agricultural input factors (Zhou and Su 2020). The present study also analyzed the relationship between late-rice yield per unit area with agricultural input factors (total power of agricultural machinery, total irrigated area, total rural electricity consumption, total applied chemical fertilizer amount) in Guiyang, and found that the former three agricultural input factors were significantly positively correlated with late-rice yield per unit area (Table 8). These findings which are consistent with other the observations of previous studies (Liu 2018, Zhou and Su 2020). In other words, agricultural input level usually has a positive effect on the increase of rice yield. So far no significant positive relationship was found here between the yield of late-rice with total applied chemical fertilizer amount one of the reason might be that because fertilizers were usually applied more during tobacco-planting, so fertilization is very disorderly during the period of late-rice planting in Guiyang, according to the information of fertilization survey conducted to the tobacco-planting formers, some could continue to use chemical fertilizers normally for late-rice planting, but some only applied a small amount of chemical fertilizers according to the growth of late-rice, and some even did not apply any chemical fertilizer, the diversity of late-rice fertilization weakens the effect of chemical fertilizer application on the yield

Table 8. Optimal regression models between agricultural input factors and late-rice yield per unit area (y).

Agricultural input factor	Optimal regression model	R^2	Rmse	P
Total power of agricultural machinery $\times 10^4$ kwa	$Y = -0.0002x^2 + 2.661x - 7920.7$	0.902^{**}	11.84	0.000
Total irrigated area $\times 10^3$ hm^2	$Y = -5\times10^{-5}x^2 + 0.6145x - 1776.6$	0.796^{**}	6.00	0.001
Total rural electricity consumption $\times 10^4$ kwa h^{-1}	$Y = -0.0367x^2 + 461.3x - 1\times10^6$	0.914^{**}	1933.29	0.000
Total applied chemical fertilizers $\times 10^4$ t	$Y = -1.0372x^2 + 15.022x + 8.5988$	0.576	246.78	0.857

per unit area of late rice. In terms of the relationship between climate conditions and late-rice yield per unit area, the present results differ in with different previous studies forv example, Su *et al.* (2020) late-rice yield per unit would decrease in Nanjing but increase in Nanchang and Hunan with temperature rise (Chen *et al*. 2017, Liu 2018).

The present study showed that days with mean daily temperature ≥ 30ºC or daily highest temperature ≥ 35°C were meanly 7.7 and 7.5 d, and days with mean daily temperature < 15ºC was meanly 6.4 d, respectively in the late growth stages of late-rice in Guiyang, which disclosed the possible occurrence of damage of high and low temperatures to late-rice. In term of tobacco-planting, the antedisplacement of the transplanting date of tobacco have been explored in order to avoid the damage to tobacco resulted from high-temperature forced precocity (Li *et al*. 2012, Lu and Xie 2013, which also could prolong the growth period of late-rice, thus is helpful for the normal growth and yield-formation of late-rice to a certain extent, but under the current premise that it is difficult to adjust the field growth period of tobacco more suitable for late-rice growth, another effective measure should be to breed late-rice varieties with short growth period and high tolerance to both high and low temperatures.

The present study revealed that climate parameters changed generally complexly and irregularly with year during late-rice growth period in Guiyang County, only the temperature (mean temperature, daily highest and lowest temperatures) in the booting-heading stage showed the significant increase trend with year. For late-rice normal growth, sunshine hours and precipitation were low but relative humidity was suitable in the whole growth period of late-rice, the temperature was suitable in the transplanting-tillering stage but low in the booting-heading and milk ripeness-mature stages, and there was possible occurrence of the damages due to high and low temperatures in the booting-mature stages. Sunshine hours, mean temperature and mean daily highest temperature in the booting-heading stage were significantly positively correlated with the yield per unit area of late-rice, and daily highest temperature affected late-rice yield most, followed by mean daily temperature, while the influence of sunshine hours was the least. Late rice varieties with short growth period and high tolerance to both high and low temperatures should be bred in agricultural production.

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