Impact of High Temperature at Flowering on Midseason Rice Yield

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Abstract: The main target of the paper is exploiting the change of the maximum temperature during midseason rice flowering period, and its impact on the yield of midseason rice. Based on the statistical data on weather in 7 provinces during 15 years, the midseason rice function models are built up, with temperature variables included. Our result shows that the maximum temperatures during midseason rice flowering periods have increasing trend with a substantial fluctuation, with great differences among regions. When the maximum temperature is between 35℃ to 39℃, the average yield of midseason rice will not change significantly, but if the maximum temperature is above 39℃, the average yield of mid-season rice will decrease by 13 percent.

Key words: climate change; the maximum temperature; midseason rice production; the Yangtze River Basin

水稻花期高温对产量的影响研究

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摘　要：为了分析中稻花期高温的变化及其对中稻产量的影响，利用 1991－2005年气象统计数据及对 7个省份中稻生产数据的描述性统计分析，建立了中稻生产定量分析函数模型，每个方程中除了包含传统的生产投入变量、技术进步变量等外，还分别包含 7种类型的气温变量。结果表明，21世纪以来，长江流域中稻花期的极端高温呈升高趋势，并伴随较大幅度的波动，且各地区增长幅度存在较大差异；当极端高温处于 35℃到 39℃之间，中稻的平均产量与 35℃以下情况无显著差异，但当极端高温达 39℃以上时，平均产量会显著降低 13%。

关键词：气候变化；极端高温；中稻生产；长江流域
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Climate change has received an increasing attention since the past century[1~6], in which, global warming is the issue concerned most[7~10]. Although policymakers are actively seeking for feasible solutions, many evidences indicate that the condition is not change as expected. Along with the average temperature rising, extreme high temperature events have occurred more frequently[11]. Climate change has created significant impacts on many aspects, among which the effects on agriculture have drawn many attentions across the world.

The impact on rice yield of high temperature during rice flowering season is one of the most concerned issues in China. Zhao *et al*.[12] have argued that high temperature in Yangtze River Basin has significant impact on midseason rice yield, but the impact on early-rice yield is not significant, based on their collected data on 48 early-rice and 30 midseason-rice in 6 provinces of Yangtze River Basin. As the high temperature during flowering season can make the pollen lose vitality, the yield of midseason rice will decreases. Li *et al*.[13] prove

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that when temperature is above 35℃, humidity is between 65~70% and the wind speed is above level 4, rice pollen will lose vitality in 0.5 h. By controlling the temperature during midseason rice flowering, Zhang *et al*.[14] get the same conclusion that rice pollen vitality drops significantly after a 40℃ treatment and then recovers gradually. They also emphasize that the most serious damage to rice pollen happens at the treatment day or the next day. Meanwhile, they also find that the activity of rice pollen has a relation with the seed setting ratio, empty grain ratio, immaturity grain ratio, which is important for yield contribution.

Through the review of literatures, it's found that agricultural scientist effectively evaluate the impact on rice under high temperature at midseason rice flowering by analyzing the data about rice pollen vitality collected from observation spots or controlled experimental field. However, there are very little studies which analyze directly the relation between high temperature and rice yield. Because farmers have learned to make adaptive adjustment to high temperature at rice flowering, the effect will be also included and assessed in these studies. In this paper, we attempt to quantitatively analyze the impact of high temperature at rice flowering on midseason rice by adopting econometric methods, based on the detail data at provincial level.

1 Materials and Methods

1.1 Materials

The provinces included in this study are Anhui, Jiangsu, Shanghai, Henan, Hubei, Sichuan and Zhejiang. Midseason rice grows generally from May to October, and flowers almost in August, which is one of the hottest months in these regions. In addition, rice always flowers in general from 12:00 to 13:00 during the day. Therefore, midseason rice often encounters high temperature during its flowering. In order to examine the impact of high temperature at rice flowering on its yield, the maximum temperature during rice flowering period was chosen as a temperature variable. It values the maximum temperature during August in the capital of each province and was collected from "*China Agricultural Statistical Yearbook*". Data about midseason rice yield were collected from "*China Statistical Yearbook*", and the production inputs data were collected from "*National Agricultural Cost-benefit Yearbook*".

1.2 Methods

Statistic analysis and multiple regression analysis were used in this study, so as to measure the impact of high temperature at flowering on midseason rice yield. Statistic analysis was used to measure the change of maximum temperature at flowering between periods and provinces and the relevance between maximum temperature at flowering and midseason rice yield.

Because some factors —— production inputs, natural disasters *et al*. —— could not be controlled under statistic analysis, its result does not exactly reflect the impact of maximum temperature at flowering, multiple regression analysis was used. We establish a production function model. In this model, the variables of production inputs, technological advance variables, natural disasters and regional variables are inclueded, the variables of maximum temperature are carefully considered and also incorporated. The model is expressed as flowing:

$$\ln(\text{yield}) = f(\text{the maximum temperature, production inputs, natural disasters, technological advance, region}) \quad (1)$$

Some study has clarified that the activity of rice pollen will decrease when the temperature is above 35℃[15], and study on pollen-kill also argues that the rice pollen will be damaged when the temperature is between 43℃ to 45℃ in 5 to 10 min[16]. It seems that there is possibly a critical temperature, above which the rice yields will decrease significantly. However, the critical temperature above which the rice yield will decrease significantly in production is still not clarified So in this study, 35℃, 36℃, 37℃, 38℃, 39℃ were set as critical temperature in 5 models respectively, to distinguish the different effect of the maximum temperature on the yield of midseason rice Moreover, in order to clarify whether there exists a linear or non-linear relationship between rice yield and the maximum temperature during rice flowering period, a linear model and a non-linear model (square of the maximum temperature was included in the model) were set up separately

The inputs in rice production considered in this study include labor, fertilizer and machinery and the-other-material inputs, labor usage including family labor input and employment, fertilizer and machinery are standardized by being divided into pesticides and fertilizer price index and machinery price index respectively, the other material inputs are standardized by divided into agricultural production inputs price index Natural disaster is reflected by the variable of the proportion of rice arable land destroyed by flood or drought The impact of technological advance on midseason rice is measured by time series t Regional variables are measured by dummy variable, Anhui is the control province

2 Results

2 1 Change of the maximum temperature at midseason rice flowering

Fig 1 shows the change of the maximum temperature during midseason rice flowering from 1991 to 2005. In the early 1990s, the maximum temperature during midseason rice flowering is about 34℃ averagely and suitable for rice growth During 1994 to 2001, the maximum temperature is stable between 34 5 and 36 0℃. However, the temperature fluctuate violently from 2002 to 2005 As shown in Fig 1, the maximum temperature rises to 36 7℃ in 2003 from 34. 3℃ in 2002, drops to 34. 3℃ in 2004, and then recover to 36 7℃ again in 2005 Although the maximum temperature fluctuates dramatically in the latest 15 years, there exists a rising trend in general

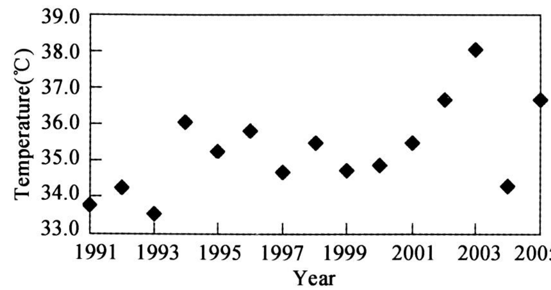

Fig 1 Change of the maximum temperature during midseason rice flowering period in the Yangtze River Basin

Note The maximum temperature of each year is weighted by the sown area in each province

The change of the maximum temperature during midseason rice varies significantly across different province (Fig 2). As shown in Fig 2, the maximum temperature during midseason rice increases remarkably in each province except Sichuan Jiangsu is the province where the average maximum temperature increases most, which increases from 33 7℃ in average in 1990s to 36. 8℃ in the first 6 years of the 21 century. As for Anhui, Shanghai, Hubei, Zhejiang, Hunan, the maximum temperature during midseason rice increases increase from 36 0℃, 35. 0℃, 36 6℃, 37. 0℃, 34 8℃ to 37. 6℃, 36 1℃, 37. 7℃, 37. 7℃ and 35 4℃ respectively. Although the temperature rise in Anhui, Hubei, Zhejiang are less than that in Jiangsu, but their maximum temperature are also quite high, in the first 6 years The average

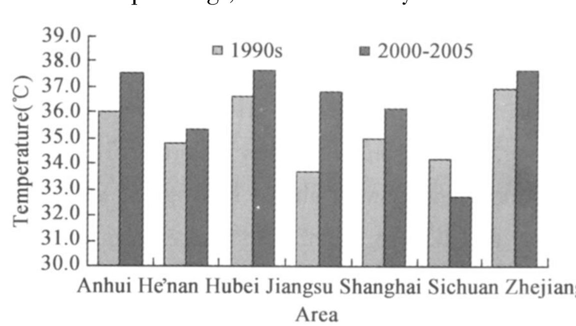

Fig 2 Change of the maximum temperature at midseason rice flowering

Note The maximum temperature is the average of each year maximum temperature during midseason rice flowering is over 37.0℃ in each provinces.

2.2 Rice yield and the maximum temperature

Fig. 3 shows the relationship between the maximum temperature at rice flowering and midseason rice yield from 1991 to 2005. The average yield of midseason rice is 7.3 t/hm^2 as the maximum temperature is below 35.0℃. When the maximum temperature rises to 35.0~36.0℃ and 36.0~37.0℃, the average yield will also increase to 7.5 t/hm^2 and 7.6 t/hm^2 respectively. However the midseason rice yield drops to 7.2 t/hm^2, when the maximum temperature continuously increase to 38.0~39.0℃. Furthermore, the yield will drop remarkably to less than 6.5 t/hm^2 when the maximum temperature is above 39℃. According to the results, the maximum temperature during midseason rice flowering period is generally from 35℃ to 37℃ in 1990s which is good for rice growth, but the rising maximum temperature in the beginning of this century, is bad for rice yield.

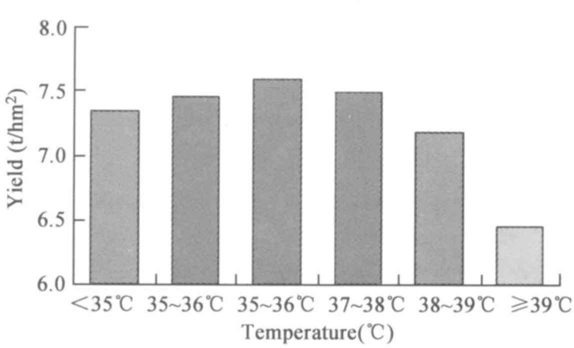

Fig. 3 The relationship between midseason rice yield and the maximum temperature during its flowering period

Table 1 shows the estimated results of production function model. There are high explainable powers of our regression equations, as R^2 is between 0.57 and 0.64. Meanwhile, the F statistical tests and Chi^2 statistical test also significant. In addition, we can find that almost all coefficients have the sign as expected, and many of them are statistically significant. As for the region dummy variables, Hubei, Jiangsu and Sichuan are statistically significant at 0.05 level, which indicates that there are some other.

The coefficients of the maximum temperature are negative in model Ⅰ and positive in model Ⅱ. The square of the maximum temperature is negative in model Ⅱ, which is consistent with our expectation. However, its coefficients are not significant. From model Ⅲ to model Ⅵ, the coefficient of the maximum temperature dummy variables are negative and not statistically significant. In model Ⅶ, the coefficient of the maximum temperature dummy variable is −0.130, and is significant at $P < 0.01$. The estimation result indicates that the impacts of the maximum temperature on midseason rice yield are completely different as the temperature in different ranges. When the maximum temperature is between 35℃ to 39℃, the average yield of midseason rice will not change significantly, but if the maximum temperature is above 39℃, the average yield of midseason rice will decrease by 13 percent.

In all models, the coefficients of technological progress variable (time t in Table 1) are statistical significant, which implies that technology plays an important role in promoting midseason rice yield in the latest 15 years. As for the other production inputs variables, the coefficients of fertilizer, labor and other-material-inputs are not statistically significant, except the input of machinery. The coefficients of machinery inputs are all statically significant at 0.05 level. This means that the increasing input of machinery will significantly contribute to the yield of midseason rice. The coefficient of flood disaster is significantly negative in all regression models, which shows flood disaster is one of the key factors adversely affecting the yield of midseason rice. As to the drought, the insignificant coefficient indicates that it is not so serious in the selected regions and period.

3 Conclusions and discussion

The maximum temperature during flowering period of midseason rice has a rising trend in

Table 1 Regression result of midseason rice production model

Explanatory variables	ln(yield)						
	Model I	Model II	Model III	Model IV	Model V	Model VI	Model VII
Constant	1.852	1.173	1.639	1.646	1.692	1.689	1.794
	(6.74)***	(1.46)	(6.97)***	(7.01)***	(7.08)***	(7.06)***	(8.16)***
Technical progress							
Time series	0.008	0.008	0.008	0.008	0.008	0.008	0.008
	(1.87)*	(2.00)**	(1.83)*	(1.89)*	(1.91)*	(1.97)*	(2.13)**
Production inputs							
ln(fertilizer)	−0.07	−0.075	−0.066	−0.07	−0.082	−0.07	−0.092
	(−1.11)	(−1.18)	(−1.04)	(−1.09)	(−1.26)	(−1.11)	(−1.56)
ln(machinery)	0.090	0.086	0.085	0.084	0.085	0.084	0.070
	(3.02)***	(2.85)***	(2.84)***	(2.83)***	(2.88)***	(2.85)***	(2.55)**
ln(other material inputs)	0.074	0.07	0.067	0.067	0.07	0.068	0.06
	(1.54)	(1.47)	(1.4)	(1.4)	(1.46)	(1.43)	(1.34)
ln(labor)	0.086	0.078	0.096	0.093	0.082	0.078	0.054
	(1.27)	(1.14)	(1.39)	(1.36)	(1.18)	(1.11)	(0.84)
Nautural disaster							
Flood ratio	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003	−0.003
	(−2.81)***	(−2.75)***	(−2.7)***	(−2.67)***	(−2.65)***	(−2.69)***	(−2.99)***
Drought ratio	0.001	0.001	0.001	0.001	0.001	0.001	0.000
	(0.74)	(0.72)	(0.76)	(0.71)	(0.78)	(0.64)	(0.17)
Temperature variables							
The maximum temperature	−0.006	0.036					
	(−1.42)	0.77					
The square of temperature		−0.001					
		(−0.90)					
Temperature dummy variables							
35℃ (1= ≥35℃, 0= < 35℃)			−0.008				
			(−0.43)				
36℃ (1= ≥36℃, 0= < 36℃)				−0.007			
				(−0.39)			
37℃ (1= ≥37℃, 0= < 37℃)					−0.017		
					(−0.95)		
38℃ (1= ≥38℃, 0= < 38℃)						−0.02	
						(−0.90)	
39℃ (1= ≥39℃, 0= < 39℃)							−0.130
							(−3.97)***
Sample Size	105	105	105	105	105	105	105
R^2	0.58	0.59	0.57	0.57	0.58	0.58	0.64

Note: The figures in parentheses are t values of estimates. ***, ** and * denote significant difference at 1%, 5% and 10% level, respectively. The province dummy variables are omitted.

our exploited periods. In the national level, the maximum temperature increase in general with great fluctuation. At provincial level, the rising trend is more significant in our explored provinces.

Although there is difference in critical temperature between Indica and Japonica varieties, it is commonly considered that hot temperature abover 35℃ has a negative effect on rice yield formation by killing rice pollen[13,16]. In this study, the maximum temperature at rice flowering was used as a temperature variable in production model, our results show that only when the maximum temperature is above 39℃, the yield of midseason rice will drop significantly. The difference may be caused by two possible reason: ① 35℃ is a critical temperature observed in experiment, under which pollen will be hurt. ② Rice flowering may be continual for several days, even pollen was killed under high temperature, insemination could carry on if the temperature is suitable in other time.

In this study, humidity and wind speed were not included in the production model for lack of data. Those two factors will also interfere with rice insemination under high temperature[13].

The goal of this work mainly focused on the impact of high temperature at flowering on rice yield. It is clear that when the maximum temperature is above 39℃, the average yield of midseason rice will drop by 13 percent significantly. Obviousely, China is confronting a great challenge by rising maximum temperature in production of midseason rice. So it is quite necessary for Chinese government to pay more attention to the changing trend and possible effects on China's agriculture, and to figure out good ways to avoid the damage by the extreme temperature in the future.

参 考 文 献

[1] Rosenzweig C, Parry M L. Potential impact of climate change on world food supply[J]. Nature, 1994, 367: 133-138.

[2] Karl T R, Knight R W, Plummer N. Trends in high-frequency climate variability in the twentieth century[J]. Nature, 1995, 377: 217-220.

[3] Schneider S H. What is 'dangerous' climate change[J]? Nature, 2001, 411: 17-19.

[4] Bakkenes M, Alkemade J R M, Ihle F, *et al*. Assessing effects of forecasted climate change on the diversity and distribution of European higher plants for 2050[J]. Global Change Biol., 2002, 8(4): 390-407.

[5] Xu Y L, Zhang Y, Lin E, *et al*. Analyses on the climate change responses over China under SRES B2 scenario using PRECIS[J]. Chinese Sci Bull, 2006, 51(18): 2260-2267.

[6] "National climate change assessment report" writing Commission. National climate change assessment report[M]. Beijing: Science and Technology Press, 2007(in Chinese).

[7] Schelling T C. Some economics of global warming[J]. Am. Eco Rev., 1992, 82(1): 1-14.

[8] Cline W R. The impact of global warming of agriculture: comment[J]. Am. Eco. Rev., 1996, 86(5): 1309-1311.

[9] Cui H Q, Zhang Z Q, Wang H Y. A new way to slow down mitigate global climate change[J]. J Liaoning Tech Univ, 2003, 22(Suppl): 112-113(in Chinese).

[10] Feng R F, Yang W Q, Zhang J. Artificial forest management for global change mitigation[J]. Acta Ecolo. Sin, 2006, 26(11): 3870-3877(in Chinese).

[11] Houghton J T, Ding Y, Griggs D J, *et al*. Climate Change 2001: The Scientific Basis[M]. London: Cambridge University Press, 2001, 26.

[12] Zhao H Y, Yao F M, Zhang Y, *et al*. Correlation analysis of rice seed setting rate and weight of 1000-grain and agrometeorology over the middle and lower reaches of the Yangtze river[J]. Sci Agric Sin, 2006, 39: 1765-1771(in Chinese).

[13] Li X Z, Liang M Z, Zhou G Q, *et al*. Effect of environment condition on pollen vigor and seed set during flowing time of rice[J]. Acta Agron Sin., 2002, 28(3): 417-420(in Chinese).

[14] Zhang B, Rui W Y, Zheng J C, *et al*. Responses of pollen activity and seed setting of rice to high temperature of heading period[J]. Acta Agron. Sin, 2007, 33(7): 1177-1181(in Chinese).

[15] Barry S, Cai Y L. Climate change and agriculture in China[J]. Global Environ Change, 1996, 6(3): 205-214.

[16] Shen Z T. Crop Breeding Experiment[M]. Beijing: China's Agricultural Press, 1995(in Chinese).