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The Impact of Extreme Temperatures on Grain Production in the Huaihe River Basin

Na Jin *, Lijing Guo

School of Economics, Anhui University of Finance and Economics, Bengbu, China
*** Corresponding author:** Na Jin (Email: 1410474155@qq.com)

Abstract: The Huaihe River Basin is an important major grain producing area in China, maintaining the stability of grain output is of great significance to food security. However, with global warming, the frequency of extreme temperature events has increased, and the frequent meteorological disasters have brought great challenges to the stable supply of food production. In this paper, the impact of extreme temperature on grain production in the Huaihe River Basin was analyzed by using the daily temperature and agricultural production related data of 28 prefecture-level cities in the Huaihe River Ecological Economic Belt from 2001 to 2020. The following conclusions are drawn: 1) The influence coefficient of extreme high temperature on grain production in the Huaihe River Basin is -0.021, extreme low temperature has no significant impact on food production. 2) The effects of extreme temperature on food production in different regions in the river basin were heterogeneous, but the overall impact was negative. The influence coefficients of extremely high temperature days on the eastern region and Midwest region were -0.035 and -0.052, respectively, while the influence coefficients of extremely low temperature days on the eastern region were -0.413. The results showed that the increase in the number of extremely high temperature days would reduce production in the eastern region andMidwest region of the basin, while the northern region was not significantly affected by extreme heat. The increase in the number of extremely low temperature days will reduce grain production in the eastern region, and the impact on the Midwest region and the northern region will not be significant. Based on the above conclusions, three suggestions are put forward to maintain the safety of food production in the Huaihe River Basin: 1) enhance the ability to detect climate change in the basin; 2) Protect the stability of grain cultivated land in the river basin; 3) Innovative breeding of climate-resilient food crop seeds.

Keywords: Extreme Temperatures; Food Production; Huaiheriver Basin; Regional Heterogeneity.

1. Introduction

Temperature is an important indicator of climate change, and the earth's surface temperature has warmed significantly in the past hundred years. According to the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC), the average global surface temperature increased by 1.1°C between 2011 and 2020 compared to 1850-1990. Extreme temperature refers to the serious deviation of temperature, compared with the average temperature, extreme temperature has the characteristics of small probability of occurrence and large social impact, and is more likely to cause more serious consequences and greater losses to ecosystems and social production. The cultivated land area of the Huaihe River Basin is 36,000 square kilometers, and grain output accounts for 20% of the country's total output, which plays a decisive role in China's agricultural production. However, it is in the north-south climate transition zone, and the temperature change trend is obvious. It is manifested as hot summer, cold and frosty winter, and extreme temperature superimposed on abnormal precipitation causes drought and flood disasters, which poses a great threat to grain in the basin. In 2022, affected by low rainfall and continuous high temperatures, the drought area of grain crops in Henan, Anhui and Jiangsu provinces in the basin in August was as high as 15.2 million mu, and the loss of grain production in some areas was serious. The report of the 20th National Congress of the Communist Party of China pointed out that Chinese's rice bowl should be firmly in his own hands. In order to stabilize food supply and effectively protect against and respond to major agricultural disasters, it is necessary to enhance agriculture's ability to cope with extreme weather and strengthen research on the impact of medium- and long-term climate change on agricultural production. Therefore, under the situation of increasing food demand and gradual deterioration of food production conditions and climatic environment, it is of great practical significance to explore the impact of extreme temperature on food production in the Huaihe River Basin.

2. Literature Review

The current research on temperature change and the impact on food production is mainly divided into two aspects. These include extreme temperature changes and their impact on crop growth and yield.

Evolution of extreme temperatures and their distribution. Taking China as the research area, the study found that the whole and most regions of China showed a warming trend, and the increase rate of extreme low temperature was higher than that of extreme high temperature, but the frequency of extreme high temperature was higher. For example, Wu Limei [1] (2016) used M-K trend test and spatial cold and hot spot analysis to analyze extreme temperatures. It is pointed out that under the background of global warming, the overall annual extreme high and low temperature in the country showed a significant warming trend from 1983 to 2012, and the average warming rates were 0.43 and 0.25 °C· 10 a)-1, and there are significant regional differences in annual extreme high and low temperature changes. Sun Ying [2] (2015) selected daily ground observation data from 192 stations in China from 1953 to

2013 to study the trend changes and spatial distribution characteristics of extreme temperature in China, and concluded that extreme high temperature only has a downward trend in the lower reaches of the Yellow River, Xinjiang and Yunnan in China, and other regions have a significant growth trend. Among them, the growth trend of extreme low temperature is greater than the growth trend of extreme high temperature, and from the perspective of frequency of occurrence, extreme high temperature tends to be more extreme, and the frequency of extreme high temperature is greater than that of extreme low temperature. In addition, Kong Feng [3] (2020) studied the spatial differentiation characteristics of extreme temperature trends in China, pointing out that there were differences in different regions, with extreme maximum temperatures showing a downward trend in Tibet and an upward trend in other regions, while extreme minimum temperatures showed a nationwide increase trend, and the increase trend rate in most regions exceeded 0.4 °C/10 a. At the regional research level, Xu Jie [4] (2022) studied the trend of extreme climate change in Ningxia based on the meteorological data of 19 meteorological stations in Ningxia, and pointed out that from 1987 to 1992, the extreme high temperature index in Ningxia rose ahead of the extreme low temperature index, indicating that high temperature events increased and low temperature events decreased in Ningxia. Chen Tianyu [5] (2023) analyzed the temporal and spatial variation characteristics of extreme minimum and maximum annual temperatures in the Yangtze River Basin using temperature data from 137 stations in the Yangtze River Basin from 1962 to 2021. The results show that the annual extreme minimum and maximum temperatures in the Yangtze River Basin show a significant increase trend, with growth rates of 0.35°C/10a and 0.26°C/10a, respectively. However, most of the sites had mutations in extreme maximum temperatures, with the highest number of mutations occurring in the early 21st century. Sun Yuyan [6] (2019) used 26 extreme temperature indices to analyze the temporal and spatial variation characteristics of extreme temperature in the Huaihe River Basin based on the daily temperature data of the Huaihe River Basin. The results show that the extreme temperature index basically shows an upward trend, but the extreme low temperature increases more than the extreme high temperature. Regionally, there are also differences in the timing of sudden changes in extreme temperatures due to differences in latitude and longitude altitude.

Effects of extreme temperatures on crop growth and yield. Extreme temperatures affect food growth and thus yields by affecting the heat resources in crop growth. Extreme heat often has an impact on the growth of rice and corn. Zhou Mengzi [7] (2017) analyzed the effect of extreme summer heat days on maize yield at the provincial scale, pointing out that in different provinces of China, when the high temperature index increased by one standard deviation, the yield reduction range of maize was -1.56%-15.06%, with Northeast China and North China producing the most serious decreases. Yin Xiaogang [8] (2015) analyzed the spatiotemporal distribution characteristics of high temperature risk during the growth period of maize in the northeast agricultural area from 1961 to 2010 and its possible impact on maize production. The results showed that maize in the agricultural area of Northeast China was most sensitive to high temperature at flowering and filling stage, and high temperature stress during this period would seriously affect maize yield, and high temperature was often accompanied by drought, which further aggravated the risk of maize yield reduction. Studies have shown that short-term extreme heat increases maize pests, resulting in a further decline in yield (Quan Yudong [9], 2015). At the same time, many studies have shown that rice is susceptible to high temperature stress during the flowering period, and the sterilization of flowers caused by high temperature is an important reason for the decline of rice yield (Zhu Zhen [10], 2015; Jiang Min [11], 2010). Very low temperatures often adversely affect wheat growth. Qian Yonglan [12] (2014) pointed out that low temperature disasters are one of the main disasters of winter wheat in North China, which can occur during the whole growth period. Through the study of low temperature disasters of winter wheat in North China, it is found that the frequency and intensity of low temperature disasters in the growing season of winter wheat in North China have shown a decreasing trend with the past 50 years, and the regional performance is that the eastern part of North China changes faster than the western part of China. In different stages of development of winter wheat, there were obvious differences in the frequency of low temperature disasters, and the frequency of low temperature disasters in the wintering and rejuvenation stages of winter wheat showed a significant decreasing trend with the age, while the frequency of low temperature disasters in the development stages of winter wheat such as tillers, jointing and ear pumping remained at a high level. Chen Xiang [13] (2021) also pointed out that in recent years, the frequent occurrence of low temperature disasters in wheat, especially the spring cold disaster in the jointing-gestation stage, has become one of the important factors restricting wheat yield and quality.

Through the above literature review, it can be found that under the background of global warming, extreme temperature generally shows an upward trend, but there are certain differences in the region, and the frequency of extreme high temperature events is significantly higher than that of extreme low temperature. Extreme temperatures adversely affect crop diseases and pests during different crop growing periods, and reduce food yields due to drought. The impact of extreme temperatures on food production is manifested in extreme high or low temperatures, which can impair the whole process of seedling development, flowering, pollination, fruiting growth and development of food crops. The main food crops in the Huai River Basin are maize, rice and wheat. The main growing period for maize is from June to October, and the main planting time for rice is from April to October. The wheat crop is sown around October and harvested around June of the following year. Many studies have shown that when the maximum temperature exceeds 35°C, the development pollination of maize and rice will be inhibited, and pollen activity will decrease, which will seriously affect the fruiting rate and cause a direct reduction in grain yield. When the temperature is below the biological zero of the crops, the crop is prone to frost damage, causing the wheat seedlings to turn yellow and die. The biological zero of rice and maize is 10°C, and the biological zero of wheat is 5°C, and when the minimum temperature of the day is lower than 5°C, the respiration of grain is weakened, and cold damage is prone to occur, resulting in reduced yield. In addition, due to differences in geographical location, climate resource conditions, temperature changes and precipitation distribution, the frequency of extreme weather is different in different regions, and the impact on food production is

different.

Based on this, this paper uses the daily maximum temperature, daily minimum temperature and agricultural production data of 28 prefecture-level cities in theHuaihe River Ecological Economic Belt from 2001 to 2020 to construct a production function with extreme temperature indicators to explore the impact of extreme temperature on grain production and regional heterogeneity in the Huaihe River Basin, so as to provide reference for preventing future climate change, coping with the adverse effects of extreme climate on food production, and maintaining the stability of grain output in the basin.

3. Research Data and Model Setting

3.1. Research Data

3.1.1. Study Area

In 2018, the National Development and Reform Commission issued the Huaihe Ecological Economic Belt, pointing out that the Huaihe Ecological Economic Belt includes 25 prefecture-level cities and 4 counties, including 7 prefecture-level cities such as Huai'an City in Jiangsu Province, 4 prefecture-level cities such asZaozhuang City in Shandong Province, 8 prefecture-level cities such as Bengbu City in Anhui Province, 6 prefecture-level cities such as Xinyang City in Henan Province and Tongbai County in Nanyang City, and 3 counties including Suixian County in Suizhou City, Guangshui City and Dawu County in Xiaogan City in Hubei Province. Considering the availability and comparability of data, this paper defines the Huaihe River Ecological Economic Belt as all 28 prefecture-level cities involved in the "planning" (including 3 prefecture-level cities where 4 counties are located). According to the planning of the Huaihe River Ecological Economic Belt, three major areas are defined. the eastern sea-river-lake linkage zone includes fivecities: Huai'an, Yancheng, Yangzhou, Taizhou and Chuzhou; The northern Huaihai Economic Zone includes 10 cities in Xuzhou, Lianyungang, Suqian, Huaibei, Suzhou, Zaozhuang, Jining, Linyi, Heze and Shangqiu; The central and western inland rise areas include 13 cities: Bengbu, Huainan, Fuyang, Lu'an, Bozhou, Luohe, Pingdingshan, Nanyang, Xinyang, Zhoukou, Zhumadian, Suizhou and Xiaogan. The28cities are divided into the eastern region, the central and western region and the northern region. The division is shown in Table 1.

Table 1. Study area division

Divide the area	Cities
Eastern region	Huai'an, Yancheng, Yangzhou, Taizhou, Chuzhou
Midwest	Bengbu, Huainan, Fuyang, Lu'an, Bozhou, Luohe, Pingdingshan, Nanyang, Xinyang, Zhoukou, Zhumadian, Suizhou, Xiaogan
North	Xuzhou, Lianyungang, Suqian, Huaibei, Suzhou, Zaozhuang, Jining, Linyi, Heze, Shangqiu

3.1.2. Data Sources

Panel data from 28 prefectures and cities in the Huaihe River Ecological Economic Zone from 2001 to 2020 were used to verify the impact of extreme temperatures on food production. The data on grain production are obtained from the China Regional Economic Statistical Yearbook, the statistical yearbooks of Anhui, Jiangsu, Henan, Shandong and Hubei provinces, and the statistical yearbooks of various cities and cities. Temperature data is from the National Center for Environmental Information (NCEI) of the National Oceanic and Atmospheric Administration (NOAA).

3.2. Model Setting

3.2.1. Econometric Model

Explore the influence of extreme temperature factors on food production in the Huaihe River Basin. The production function model was constructed to investigate the influence of each input factor on grain yield, and the extreme temperature factor was introduced on the basis of the Cobb Douglas function to analyze the influence of extreme temperature on food production. The model setting is:

$$lnoutput_{it} = \alpha_0 + \sigma trend + \beta_1 lntx35_{it} + \beta_2 lntn5_{it} + \beta_3 lnb_area_{i,t} + \beta_4 lnlabor_{it} + +\beta_5 lnfertilizer + \mu_{it} \quad (1)$$

Where*i*and t represent the *t* year of the *i* city;*output*represents grain production in the Huaihe River Basin. Core extremetemperature indicators: *tx35* represents the number of extremely high temperature days with high temperature exceeding 35°C, *tn5* represents the number of extremelylow temperature days with a minimum temperature below 5 °C, and other variables include grain sown area (b_area), labor input (labor), fertilizer input (fertilizer). Trend is a technological advance represented by a temporal trend term and μrepresents a random perturbation term.

3.2.2. Variable Selection

The variable explained. The explanatory variable is measured by total food production (output). Due to the impact of extreme temperatures on grain crops such as rice, corn and wheat in the Huaihe River Basin, the total grain yield was selected as an explanatory variable to measure.

Core explanatory variables. The explanatory variables were mainly the number of very high temperature days (tx35) and the number of extremely low temperature days (tn5). The number of extreme high temperature days mainly refers to the number of days when the daily high temperature exceeds 35°C, and when the daily temperature exceeds 35°C, it will seriously affect the growth and development of food crops, and is used to reflect the impact of extreme high temperature on food production. The number of extreme low temperature days mainly refers to the number of days when the daily minimum temperature is 5 degrees Celsius below the biological zero of food crops, reflecting the impact of extreme low temperature on food production.

Other variables. In actual agricultural production, food production is not only affected by climate, but also by grain sown area, labor input, agricultural machinery, agricultural material consumption and other inputs, so the total grain sown area (b_area), the number of employees in the primary industry (labor), fertilizer use (fertilizer), Total mechanical power (tmp) was included in the model for estimation. Taking into account the impact of technological progress on agricultural production, it is incorporated into the model with the temporal trend term representing technological progress, referring to the practice of other scholars.

All the above variables were logarithmized and tailed on the 1% and 99% scores to eliminate the influence of outliers and increase model stability. The descriptive statistics for each variable are shown in Table 2.

Table 2. Variable descriptive statistics

Variable	Mean	S.D.	Min.	Max.
lnoutput (10,000 tons)	5.796	0.537	4.454	6.697
lntx35 (day)	2.234	0.773	0	3.497
lntn5(Day)	4.7923	0.113	4.500	5.037
lnb_area(10,000 hectares)	4.030	0.517	2.957	4.869
lnlabor(10,000 people)	4.832	0.646	3.447	5.963
lnfertilizer (10,000 tons)	3.454	0.557	2.067	4.467
lntmp (10,000 kWh)	6.120	0.6397	4.406	7.278
trend	10.5	5.7718	1	20

Note: The sample observation is 560.

4. Analysis of Empirical Results

4.1. Model Regression Results

First, after the robust Hausman test, a fixed-effect model was selected at a significance level of 5%. In the case that the number of time T in the panel data model is less than the number of sections N, consider using panel correction standard error (PCSE) to deal with complex panel error structures to deal with sequence correlation, heteroscedasticity, and so on. By performing heteroscedasticity and autocorrelation test on the model data, it is shown that the model has heteroscedasticity and first-order autocorrelation, so PCSE is selected for estimation. Moreover, since the total mechanical power is also an important input factor of food production, this paper tests the stability of the model by adding and deleting explanatory variables, and after deleting the explanatory variables of the model, the significance level and symbol direction of the extreme temperature index of the core explanatory variables do not change, and only minor changes occur in the coefficients, which proves that the model has a certain robustness. Table 3 reports the regression results using ordinary least squares (OLS) estimation and panel correction standard error (PCSE) estimation, and the convergence of the estimates of the two methods also indicates that the model has good robustness.

Table 3. Model regression results

	OLS	PCSE
lntx35	-0.025**	-0.021**
	(-2.39)	(-2.49)
lntn5	-0.053	-0.032
	(-0.56)	(-0.43)
lnlabor	0.050	0.067
	(1.33)	(1.64)
lnb_area	0.658***	0.625***
	(6.14)	(17.89)
lnfertilizer	0.199***	0.216***
	(4.04)	(9.27)
trend	0.017***	0.018***
	(6.59)	(9.73)
_cons	2.332***	2.140***
	(5.27)	(5.70)
N	560	560

Note: The values in parentheses are T statistics; ***, **and * represent passing the significance test at the 1%, 5%, and 10% levels, respectively. Same below.

It can be seen from the column (2) of the regression results that the number of extremely high temperature days has a negative impact on grain production, and the influence coefficient of extremely high temperature days is significant at the significance level of 5%, and the impact coefficient is -0.021. It has been shown that an increase in the number of extremely high temperature days causes a decrease in food production. The reason is that extreme heat in summer will increase pests and diseases and drought, and the setting rate of food crops will decrease, which will reduce food production. However, the number of extremely low temperature days showed a negative impact on food production, but failed the significance test, which may be due to the rising trend of extreme low temperature in recent years, the frequency of extremely low temperature has decreased, and the impact on food production has weakened.

From the perspective of the impact of other variables on food production, sown area, fertilizer input and technological progress all showed a significant promotion effect on food production, and although the impact coefficient of labor input on food production was positive, it failed the significance test, which is similar to the conclusion of Jiang Debo [14] (2017). In addition, the influence coefficient of grain sown area on grain production is 0.625, indicating that the size of the sown area contributes significantly to food production, and increasing the sown area can promote the increase of food production.

4.2. Analysis of Regional Heterogeneity

In order to further verify the regional heterogeneity of extreme temperature on grain production in the Huaihe River Basin, the eastern region, Midwest region and northern region were grouped and estimated. The estimated results are shown in Table 4.

Table 4. Regional heterogeneity model regression results

	Eastern region	Midwest region	North region
lntx35	-0.035*	-0.052**	-0.007
	(-1.92)	(-2.38)	(-0.67)
lntn5	-0.413**	0.213	-0.121
	(-2.51)	(1.62)	(-0.85)
lnlabor	0.136*	-0.017	-0.006
	(1.92)	(-0.38)	(-0.10)
lnb_area	0.818***	0.630***	0.809***
	(5.75)	(11.87)	(14.35)
lnfertilizer	0.093*	0.275***	0.055
	(1.65)	(5.82)	(1.33)
trend	0.013***	0.018***	0.011***
	(3.49)	(7.05)	(5.53)
_cons	3.609***	1.269*	2.887***
	(3.45)	(1.94)	(3.75)
N	100	260	200

Through the regression results, it can be seen that extreme temperature has a greater impact on the eastern, central and western regions, but has no significant impact on the northern region. The number of extremely high temperature days showed a significant negative impact on the eastern and central and western regions, and the impact coefficients were -0.035、-0.052, indicating that1% increase in the number of extremely high temperature days will reduce grain production by 0.035% in the eastern and 0.052% in central and western regions。 It can be seen that there is regional heterogeneity in the impact of extreme temperature on grain production in the Huaihe River Basin. The number of extremely low

temperature days showed a negative impact on grain yield at the significance level of 5%, and the impact coefficient was -0.413. Itshows that the eastern region is greatly affected by extreme low temperature, and an increase of 1% in the number of extreme low temperature days will reduce grain output in the eastern part of the Huaihe River Basin by 0.413%.

From the perspective of the impact of other variables on food production, labor input showed a significant positive impact in the eastern region and an insignificant negative impact on the central and western regions and the northern region, which is similar to Li Meijuan [15]. (2014) The conclusion is similar. The reasons may be twofold: on the one hand, due to the availability of data, labor input uses the number of employees in the primary industry in various cities, which cannot measure labor input in labor production well, on the other hand, this may be due to the improvement of agricultural science and technology and the degree of agricultural mechanization, labor productivity is improved, labor demand is reduced. There are positive impacts on grain output in various regions, which is consistent with the facts and experience, indicating that increasing grain sowing area, fertilizer input and improving technological progress can effectively promote regional grain production.

5. Conclusion and Recommendations

5.1. Conclusion

In the context of climate warming, extreme temperatures pose a greater threat to food production. This paper uses the daily maximum and minimum temperatures and agricultural production data of 28 prefectures and cities in the Huaihe River Ecological Economic Belt from 2001 to 2020 to construct a production function model with extreme temperature indicators, and analyzes the impact of extreme high and low temperature on grain production and regional heterogeneity by combining panel correction standard error (PCSE). The following 2 conclusions are drawn:

1) Extreme high temperature had a significant adverse effect on grain production in the Huaihe River Basin, and the impact coefficients were -0.021, indicating that a 1% increase in the number of extremely high temperature days will reduce grain production in the Huaihe River Basin by 0.021%, extreme low temperature has no significant impact on grain production in the Huaihe River Basin.

2) The impact of extreme temperature on food production in different regions in the river basin is heterogeneous. Grain production in the eastern and central and western parts of the Huaihe River Basin is sensitive to extreme temperatures. The influence coefficients of extremely high temperature days on the eastern and central and western regions were -0.035, -0.052, passed the 10% and 5% significance tests respectively. The influence coefficient of the number of extremely low temperature days on the eastern region was -0.413 and passed the 5% significance level test. The results showed that the increase in the number of extremely high temperature days would reduce the yield in the eastern and central and western regions of the river basin. The increase in the number of extremely low temperature days will reduce grain production in the eastern region, and the impact on the central and western regions and the northern region will not be significant. However, extreme temperatures had no significant impact on grain production in the northern part of the Huaihe River Basin.

5.2. Recommendations

In view of the above research and conclusions, the following three suggestions are put forward to ensure the effective response to extreme temperature changes in the Huaihe River Basin and ensure food security:

1) First of all, in view of the adverse impact of extreme temperatures on food production, we should first strengthen the monitoring capacity to address climate change, improve the construction of natural disaster prevention and control system, and improve the forecasting ability of meteorological disasters. By strengthening the monitoring of the climate and environment of the Huaihe River Basin, innovative monitoring equipment is provided to provide technical support for coping with extreme weather changes in the Huaihe River Basin.

2) Secondly, through model analysis, it can be seen that the impact of grain sowing area on food output is large, and in recent years, due to industrial land, urbanization process, environmental pollution and other problems, the effective availability of high-quality farmland has been reduced, so it is necessary to continue to ensure the arable land for food production, improve the sown area and replanting index, and then increase food production.

3) Finally, strengthen investment in agricultural technology and innovate to cultivate climate-resilient food crop seeds. Technological advances can increase national food production, thereby enhancing the resilience of food production to climate change. Under the pressure of rapid climate change and frequent extreme weather, the selection and breeding of excellent varieties is one of the most fundamental adaptation measures for agriculture to cope with climate change. Planting rice with strong high temperature and drought resistance in areas prone to high temperature and drought weather, and planting cold tolerant wheat in areas prone to extreme low temperature can increase the climatic adaptability of food crops, thereby ensuring stable food yield.

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