Agricultural Science & Technology, 2017, 18(7): 1263–1271, 1276

Impacts of Climate Change on the Occurrence Degree of Cotton Aphids in Huang-Huai-Hai and Yangtze River Basins

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Abstract **[Objective]** The aim was to analyze the impacts of climate change (temperature and precipitation) on the occurrence degree of cotton aphids. **[Method]** Econometric models were established to explore the impacts of climate change on the occurrence degree of cotton aphids based on the observation data from 50 counties in Huang-Huai-Hai and Yangtze River basins in 1991–2010, including variables on the occurrence degree of cotton aphids, temperature and precipitation, and other socio-economic factors. **[Result]** There were significant differences in the effects of temperature and precipitation changes on the occurrence degrees of cotton aphid in different growth stages, and even in the same growth stage, the cotton aphids had different responses to the changes of temperature and precipitation in different regions. **[Conclusion]** It should give full consideration to the climatic conditions in different periods of different regions, and it should adopt proper measures to control the cotton aphids on the basis of figuring out the occurrence rule of cotton aphid, so as to ensure cotton production.
Key words Cotton aphid; Occurrence degree; Temperature; Precipitation; Impacts

Cotton is an important cash crop, and in the past 10 years, the sown area of cotton in China has maintained at about 4 million to 5 million hm^2, accounting for 7% of the sown area of economic crops in China (Statistics Bureau, 2015). For cotton, besides the input factors and technological progress, diseases and insect pests are one of the important factors that affect the yield of cotton. Research has shown that in normal years, diseases and insect pests can result in a yield loss of up to 15–20%, and even 30–50 when serious[1]. In the late 1990s, before the introduction of transgenic insect-resistant cotton, cotton bollworm was a major pest affecting cotton yield [2]. With the large-scale planting of transgenic cotton, cotton bollworm has been effectively inhibited, but *Aphis gossypii* (cotton aphid) has become one of the major pests, and the yield loss caused by cotton aphid could achieve 25% when serious[3].

Among the influencing factors of cotton aphid occurrence, climate change has been the concern of the academic circles. In order to understand the impact of climate change on cotton aphid occurrence, some studies adopt indoor controlled-experiment[4-6], and others make correlation analysis on the climatic elements and the occurrence degree of cotton aphid in a certain region based on the secondary data[7-9]. However, the current studies are either conducted in the laboratory or confined to a small area (such as a certain test field in a certain county or province). There is a lack of comprehensive quantitative analysis combining different factors in large field scale within a larger range. Since the occurrence of cotton aphid is affected by

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Received: May 8, 2017 Accepted: June 16, 2017

气候变化对黄淮海和长江流域棉蚜发生程度的影响

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摘 要 [目的]分析大区域范围内大田尺度上气候变化(主要是温度和降水)对棉蚜发生程度的影响。[方法]基于黄淮海和长江流域 1991~2010 年 50 个县棉蚜发生程度的观测资料、长序列气候资料及其他社会经济数据,运用计量经济学模型定量分析了气候变化对棉蚜发生程度的影响。[结果]不同生长阶段温度和降水的变化对棉蚜发生程度的影响差异显著;即使在同一生长阶段,不同区域棉蚜对于温度和降水的反应也不一致。[结论]应该充分考虑不同地域不同时期的气候条件;在摸清棉蚜发生规律的基础上采取合适的措施加以防范,从而保障棉花生产。
关键词 棉蚜;发生程度;温度;降水;影响

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收稿日期 2017-05-08
修回日期 2017-06-16

various factors, the quantitative analysis combining the various factors in large scale fields of a larger region could get the conclusion which is more conductive for scientists to design reasonable technology and policy measures to inhibit the occurrence of cotton aphids, thereby better guiding the production practice. Then, if the quantitative analysis is carried out in large-scale field in larger region, what kind of effect will be of climate change on the occurrence of cotton aphid, and will there be any differences in the effect of climate change on cotton aphid occurrence in different regions?

In order to answer the above questions, we carried out the quantitative analysis in large-scale filed in a larger region using the observation materials from the county-level observation stations on the cotton aphid occurrence degree for many years by the natural scientists, as well as the corresponding climate data and other social and economic data. In China, cotton planting is mainly concentrated in Huang-Huai-Hai River Basin, the Yangtze River Basin and Xinjiang; in 2014, the cotton sown area in these 3 major cotton planting regions accounted for 93% of the total cotton planting area (National Bureau of Statistics, 2015). Considering the availability of data and the representativeness of the samples and regions, sampling points were selected in Hebei, Henan, Shandong, Shanxi and Shaanxi along the Huang-Huai-Hai River Basin, and Hubei, Anhui, Jiangsu along the Yangtze River Basin. The cotton planting area in these 8 provinces accounts for 46% of the total in China, and they have a wide geographical range, making the samples representative.

Literature Review

Impact of climate change on the occurrence degree of cotton aphids

Most of the existing studies are concerned about the effects of temperature changes during the different growth stages of cotton aphid (especially seedling aphid and aphid bearing periods) on its occurrence degree. The growth of a cotton aphid can be divided into 5 stages: the first stage is from September to October, when it is time to move to the winter hosts and lay eggs; the second stage is from November to February, the overwintering period; the third stage is from March to April, when it is time for the over-winter eggs to begin the incubation and move to the summer hosts, known as the incubation and migration period; the fourth stage is from May to June, when it is the seeding period of cotton, so it is also called the seedling aphid period; the fifth stage is from July to August, called the aphid bearing period, which is also the peak period of cotton aphid occurrence. LUO[7] (based on Anyang of Henan Province) and Slosser *et al.*[9] (based on Texas of the United States) carried out the correlation analysis on the observation data from cotton fields of the test stations, finding that the number of cotton aphids in seedling aphid and aphid bearing periods were in proportional relation to temperature. Some studies based on indoor controlled experiment found that there was an optimal temperature range for the cotton aphids in seedling aphid and aphid bearing periods; the number of cotton aphids would decrease if the temperature went beyond 27 ℃ in seedling aphid period, and beyond 30 ℃ in aphid bearing period[4-6]. The study based on experienced-based judgment found that the temperature rising during the wintering and incubation and migration periods was beneficial to cotton aphid overwintering or production[10]. Although not much attention is attached, there are also some studies analyzing the relationship between cotton aphid occurrence and precipitation. It has found that rainy climate would inhibit the occurrence of cotton aphids, especially in seedling aphid and aphid bearing periods[11]. It also has found that the correlation between cotton aphid occurrence and precipitation is not significant [12]. Overall, although the effect of climate change on cotton aphids is a key problem, most of the existing studies are based on indoor controlled-experiment or the observation data analysis of some special regions, and there is a lack of comprehensive quantitative analysis combining different factors in large field scale within a larger range.

Impacts of social and economic factors on the occurrence degree of cotton aphids

In addition to climatic factors, the occurrence of cotton aphids is also affected by some other social and economic factors. However, the related research is very limited, and the conclusions vary a lot. For example, some studies found that after the popularization of transgenic insect-resistant cotton, the number of beneficial insects increased due to the reduction in the application of chemical fertilizers, thereby indirectly inhibiting the occurrence of cotton aphids[13-15]. However, some other scholars believed that the leaf surface of transgenic cotton was more conductive for cotton aphids to penetrate and feed, and thus more conductive to the occurrence of cotton aphids[2, 16-17]. The crop planting structure may affect the occurrence of cotton aphids. For example, the planting area and layout of wheat would affect the growth of cotton aphid population [18-19]. In addition to wheat, the biological mechanism of controlling alfalfa with edge of cotton field was also investigated[20], but there is still no study on the effect of other crops on cotton aphids. The study of Matis *et al.* [21] showed that the lower the level of irrigation, the lower the cotton aphid mortality was. However, there is still no study analyzing the correlation between irrigation and cotton aphids. In terms of the effects of fertilization level, Matis *et al.* [21] found that the occurrence of cotton aphids is negatively correlated with the nitrogen levels, and with the increase of nitrogen fertilizer application amount, both the birth rate and mortality rate of cotton aphids decreased. However, some other studies found that the occurrence degree of cotton aphids is positively correlated with the nitrogen levels, that is, the occurrence and harm of pests would be serious in the farmland with the increase of nitrogen fertilizer application level[22-23].

Sample and Data Sources

In order to study the impact of climate change on cotton aphid occurrence, we collected 3 sets of data, namely the monitoring data of cotton aphid occurrence degree in major county-level cotton producing areas, socioeconomic data and meteorological data. Based on the availability, matching results and sample representativeness of the 3 sets of data, we selected 50 counties from 8 provinces (Henan, Hebei, Shandong, Shanxi and Shaanxi in the Huang-Huai-Hai River Basin and Hubei, Jiangsu and Anhui in the Yangtze River Basin) as the analysis samples, in which 33 counties were in the Huang-Huai-Hai River Basin, and 17 counties in the Yangtze River Basin. The time span of the 3 sets of data was from 1991 to 2010.

The collected data of county-level cotton aphid occurrence degree was the monitoring data of the field cotton aphid occurrence in some of the county-level stations in the major cotton producing areas from the Institute of Plant Protection, Chinese Academy of Agricultural Sciences. The socioeconomic data (Proportion of the sown area of transgenic insect-resistant cotton, Proportion of effective irrigation area in cultivated land area, Chemical fertilization rate, Crop planting structure) were from the county-level materials provided by the Institute of Information, Chinese Academy of Agricultural Sciences). The meteorological data were the monthly observation data about temperature and precipitation from the national meteorological stations, and spatial interpolation was used to get the meteorological data of the counties with no meteorological stations[24]. The average of these data was shown in Table 1.

Cotton Aphid Occurrence Degree and Climate Change Tendency

Cotton aphid occurrence degree.

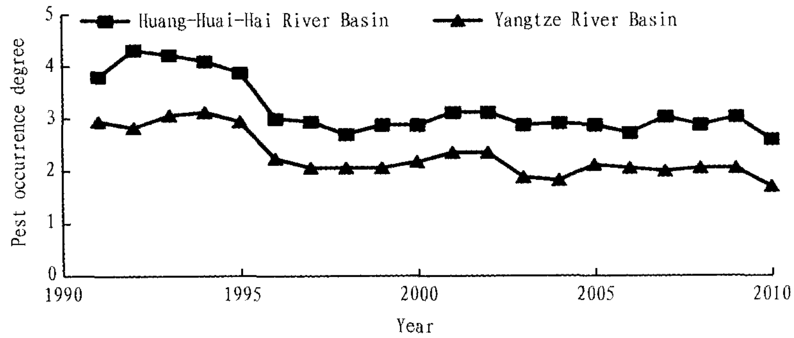
The results showed that in both the Huang-Huai-Hai River Basin and the Yangtze River Basin, despite annual fluctuations, the overall trend of cotton aphid occurrence becoming lighter, but the occurrence degree of cotton aphids in the Huang-Huai-Hai River Basin was more serious than that in the Yangtze River Basin. As shown in Fig.1, in the early 1990s, the occurrence of cotton aphids in the Huang-Huai-Hai River Basin was at level 4 or so, with the severity of above average, and after 2000, the level of cotton aphid occurrence dropped to about level 3, with the severity of below average. The changing trend was very consistent with the that in the Yangtze River Basin. In addition, throughout the investigation time span, the occurrence degree of cotton aphid was more serious in the Huang-Huai-Hai River Basin. For example, in 1990, the occurrence degree of cotton aphid was close to level 4 in the Huang-Huai-Hai River Basin, which was heavy, while the occurrence in the Yangtze River Basin was close to 3, which was in the medium level. In 2000, the occurrence degree of cotton aphid was close to level 3 in the Huang-Huai-Hai River Basin, while the occurrence was close to 2 in the Yangtze River Basin.

Climate change tendency

The average temperature and precipitation during the growth stages of cotton aphid in the first 5 years and last 5 years in 1991–2000 were used to analyze the long-term variation trend of temperature and precipitation

Table1 Descriptive statistical analysis of major variables (mean)

	Yangtze River Basin	Huang-Huai-Hai River Basin
Occurrence degree of cotton aphids (1-Slight, 2-Light, 3-Medium, 4-Heavy, 5-Serious)	2.29	3.19
Average temperature at different growth stages of cotton aphids//℃		
Autumn spawning period	20.80	17.77
Wintering period	6.61	2.50
Incubation and migration period	12.89	11.55
Seedling aphid period	23.08	22.77
Aphid bearing period	27.79	26.04
Precipitation amount at different growth stages of cotton aphids //mm		
Autumn spawning period	133.19	106.20
Wintering period	195.33	48.26
Incubation and migration period	192.39	55.16
Seedling aphid period	306.78	136.23
aphid bearing period	380.12	290.61
Proportion of the sown area of transgenic insect-resistant cotton	0.39	0.52
Proportion of effective irrigation area in cultivated land area	0.71	0.66
Chemical fertilization rate per hectare//t/hm^2	0.37	0.35
Crop planting structure (proportion of sown area)		
Cotton	0.11	0.13
Wheat	0.15	0.36
Rice	0.26	0.01
Corn	0.06	0.20
Number of samples	627	323



The data were from the Institute of Plant Protection, Chinese Academy of Agricultural Sciences.

Fig. 1 Trend of occurrence degree of cotton aphid in Huang-Huai-Hai and Yangtze River basins

Table 2 Average temperature at the different growth stages of cotton aphids in Huang-Huai-Hai and Yangtze River basins

	Autumn spawning period	Wintering period	Incubation and migration period	Seedling aphid period	Aphid bearing period
Huang-Huai-Hai River Basin					
1991–1995	17.3	2.4	10.7	22.2	26.0
2005–2010	18	2.4	11.8	23.3	25.9
Yangtze River Basin					
1991–1995	20.1	6.5	12.0	22.5	27.6
2005–2010	21.3	6.5	13.3	23.6	28.1

Table 3 Precipitation at the different growth stages of cotton aphids in Huang-Huai-Hai and Yangtze River basins

	Autumn spawning period	Wintering period	Incubation and migration period	seedling aphid period	Summar aphid period
Huang-Huai-Hai River Basin					
1991–1995	92	57	62	132	281
2005–2010	106	44	54	140	318
Yangtze River Basin					
1991–1995	132	176	217	323	367
2005–2010	149	214	169	253	409

in the 20 years. The results showed that in the 20 years, there was no change in the average temperature during the wintering period in both the 2 river basins, but the temperature during the other 3 periods (autumn spawning period, incubation and migration period and seedling aphid period) presented the rising trend, and the temperature during the autumn spawning period and incubation and migration period rose faster in the Yangtze River Basin (Table 2). For example, during the incubation and migration period, the average temperature in the Huang-Huai-Hai River Basin increased by 1.1 ℃, while the Yangtze River Basin increased by 1.3 ℃. The average temperature declined slightly during the aphid bearing period in the Huang-Huai-Hai River Basin, while temperature continued to show an upward trend in the Yangtze River Basin.

The precipitation in some growth stages of cotton aphid in the past 20 years showed similar changing trend in the Huang-Huai-Hai River Basin and Yangtze River Basin, while the changes in the other stages were different (Table 3). The precipitation in the 2 regions increased in the autumn spawning period and aphid bearing period, and the increasing range in the Yangtze River Basin was larger than that in the Huang-Huai-Hai River Basin. For instance, during autumn spawning period, the precipitation in the Huang-Huai-Hai River Basin increased by 14 mm, while the precipitation in the Yangtze River Basin increased by 17 mm. During the incubation and migration period, the precipitation in the 2 basins showed a decreasing trend, in which the precipitation in the Huang-Huai-Hai River Basin decreased by 8 mm, while the precipitation in the Yangtze River Basin decreased by 48 mm. Different from the above 3 growth stages, the changes of precipitation in the wintering period and seedling aphid period were the totally opposite in the 2 river basins. For example, the precipitation in the wintering period decreased by 14 mm in the Huang-Huai-Hai River Basin, while the precipitation increased by 38 mm in the Yangtze River Basin.

Model Setting and Results

Model setting

It needs to take comprehensive consideration to the climatic factors, popularization of insect-resistant cotton and other social and economic factors (such as irrigation, fertilization and planting structure) to clearly understand the effects of transgenic insect-resistant cotton popularization and climate change on the occurrence of cotton aphids. Therefore, the following econometric model was established:

$$Y_{it}=\beta X_{it}+\gamma Y_{i,t-1}+\delta Z_{it}+\varepsilon_{it}$$

The dependent variable Y_{it} on the left side of the model is the occurrence degree of cotton aphid in the t^{th} years of county i, and the values are 1 (slight), 2 (light), 3 (medium), 4 (heavy) and 5 (severe).

The right side of the model is the explanatory variables. Where, X_{it} is the climatic factors during the different growth stages of cotton aphids, such as temperature and precipitation/there are 5 growth stages for cotton aphid: September–October of the year before (autumn spawning period), November of the year before and February of the year (wintering period), March–April of the year (incubation and migration period), May–June of the year (seedling aphid period), July–August of the year (aphid bearing period). Variable $Y_{i,t-1}$ is the occurence degree of cotton aphid of the year before (t-1) in county i. Variable Z_{it} represents other social and economic variables, including Proportion of the sown area of transgenic insect-resistant cotton, Proportion of effective irrigation area in cultivated land area, Chemical fertilization rate//t/hectare, Crop planting structure (proportion of sown area of cotton, wheat, rice and corn in the total crop sown area); β, γ and δ are parameters to be estimated, and ε_{it} is the standard error.

In order to analyze the linear and nonlinear effects of climate variables on the occurrence of cotton aphid, as well as the effect of climate fluctuation on cotton aphid occurrence, 2 kinds of models were designed as follows: Model 1 only included the linear variables of temperature and precipitation in different growth stages of cotton aphid (one degree term); Model 2 included the linear and nonlinear variables of temperature and precipitation in different growth stages of cotton aphid (one degree and quadratic term) as well as the standard errors of temperature and precipitation. As for the 2 models, in addition to climate variables, which were different, the other variables were the same. Since there were significant differences in the natural conditions between Huang-Huai-Hai and Yangtze River basins, the samples from the 2 regions were estimated separately to analyze the effects of climate change on the occurrence degree of cotton aphid in different regions (Table 4 and Table 5).

Estimation method

Since the values 1-5 of the variable of occurrence degree of cotton aphid was a kind of discrete ranking data, there would be errors in the general linear estimation results. Therefore, the ordered Probit Model was used, which was specialized to estimate the variables of discrete data. The Ordered Probit Model is a nonlinear model, in which $Y_{i,t*}$ is the unobservable latent variable behind $Y_{i,t}$, which satisfies the following formula:

$$Y_{it}^*=\beta X_{it}+\gamma Y_{i,t-1}+\delta Z_{it}+\varepsilon_{it}$$

Where, the relationship between $Y_{i,t*}$ and $Y_{i,t}$ is as follows:

$$Y_{it}^*\begin{cases} 1 & Y^*\leqslant a_1 \\ 2 & a_1<Y^*\leqslant a_2 \\ J & Y^*\geqslant a_J \end{cases}$$

According to the standard normal distribution hypothesis, it was possible to deduce the distribution of $Y_{i,t}$ under given conditions, thereby calculating the response probability of $Y_{i,t}$:

$$P(Y_{it}=1|X)=P(Y^*\leqslant a_1|X)=P(\varepsilon_{it}\leqslant a_1-\beta X_{it}-\gamma Y_{i,t-1}-\delta Z_{it})=\varphi(a_1-\beta X_{it}-\gamma Y_{i,t-1}-\delta Z_{it})$$

$$P(Y_{it}=2|X)=P(a_1<Y^*\leqslant a_2|X)=P(a_1-\beta X_{it}-\gamma Y_{i,t-1}-\delta Z_{it}\leqslant\varepsilon_{it}\leqslant a_2-\beta X_{it}-\gamma Y_{i,t-1}-\delta Z_{it})=\varphi(a_2-\beta X_{it}-\gamma Y_{i,t-1}-\delta Z_{it})-\varphi(a_1-\beta X_{it}-\gamma Y_{i,t-1}-\delta Z_{it})$$

Where, $a_1<a_2<...<a_J$ are an unknown parameter called the cut point. And then likelihood function could be established according to the above formula, and the maximum likelihood method was used to estimate the parameters. There is no simple explanation to the number of the sorting probit coefficients, but its symbolic and statistical significance was consistent with the linear regression results[25].

Model estimation results and discussion

Impact of climate change on the occurrence degree of cotton aphid.

Impact of temperature on the occurrence degree of cotton aphid in different growth stages

There were significant differences in the effects of temperature during the growth stages of cotton aphid on the occurrence degree, and the effects varied a lot among different regions. The regression results in the Huang-Huai-Hai River Basin showed that the temperature in the autumn spawning period presented significant nonlinear correlation with the occurrence degree of cotton aphid. When the temperature was below 15.9 ℃ during the autumn spawning period, the increase of temperature was beneficial for cotton aphids to lay eggs, but if the temperature was over 15.9 ℃, the increase of temperature would inhibit the spawning. Currently, the average temperature in the region was 20.8 ℃ during the autumn spawning period, indicating that the increase of the average temperature could inhibit cotton aphids in the future. Moreover, the fluctuation of temperature during the period was conductive to the growth and reproduction of cotton aphid (Table 4). On the other hand, in the Yangtze River Basin, there was only significant negative correlation between the temperature in autumn spawning period and the occurrence of cotton aphid, but no nonlinear correlation (Table 5). It indicated that if the temperature further increased in the autumn spawning period, the occurrence degree of cotton aphid would reduce due to the decrease of eggs in the Yangtze River Basin.

In winter period, temperature rising had a significant effect on promoting the occurrence of cotton aphid in the Huang-Huai-Hai River Basin, while the effect was not significant in the Yangtze River Basin (Table 4 and 5). The estimation results of the model for Huang-Huai-Hai River Basin showed that the estimated coefficients of the linear variables were positive, which were only significant in nonlinear model, and since the quadratic term and standard deviation of temperature were not significant, the temperature was also not significant in the linear model. In other words, with other factors controlled, the increase of temperature in the wintering period would lead to the improvement of the occurrence degree in all the sampling sites or in the Huang-Huai-Hai River Basin, that is, conductive to the survival of overwintering eggs. However, in the model for the Yangtze River Basin, the several variables of temperature in wintering period were not significant either in the liner or nonlinear model, indicating that the growth of cotton aphid was not sensitive to the temperature in wintering period in the Yangtze River Basin.

The effect of the temperature variation in the incubation and migration period on the occurrence degree of cotton aphid was not significant (especially in the Yangtze River Basin), and the effect of temperature fluctuation on the occurrence degree of cotton aphid was significant mainly in the Huang-Huai-Hai River Basin (Table 4 and Table 5). The estimation results of the model for the Yangtze River Basin showed that the temperature variables in the incubation and migration period were not significant. The linear regression results of the model for the Huang-Huai-Hai River Basin showed that the temperature variables in the incubation and migration period were positive and significant, and further including the quadratic term variable and standard deviation of temperature into the model found that only the estimated coefficients of standard deviation were positive and significant, indicating that the occurrence of cotton aphid in the Huang-Huai-Hai River Basin was sensitive to temperature fluctuation, which was favorable for the incubation and migration of cotton aphids.

The changes of temperature during the seedling aphid period presented significant nonlinear relationship with the growth of cotton aphid in the

Table 4 Estimation results of econometric model of determinants of occurrence degree of cotton aphid in the Huang-Huai-Hai River Basin

	Model 1		Model 2	
	Coefficient	Standard error	*Coefficient*	Standard error
Temperature at different growth stages of cotton aphids				
Average temperature in autumn spawning period	-0.070	0.077	2.124***	0.610
Quadratic component of average temperature in autumn spawning period			-0.067***	0.017
Standard deviation of average temperature in autumn spawning period			0.181**	0.086
Average temperature in wintering period	0.044	0.067	0.262*	0.158
Quadratic component of average temperature in wintering period			-0.001	0.017
Standard deviation of average temperature in wintering period			-0.117	0.108
Average temperature in incubation and migration period	0.109*	0.058	0.077	0.592
Quadratic component of average temperature in incubation and migration period			-0.001	0.026
Standard deviation of average temperature in incubation and migration period			0.150*	0.079
Average temperature in seedling aphid period	0.029 3	0.070	-2.621***	0.930
Quadratic component of average temperature in seedling aphid period			0.058***	0.021
Standard deviation of average temperature in seedling aphid period			-0.147	0.102
Average temperature in aphid bearing period	-0.196**	0.082	-0.486	1.382
Quadratic component of average temperature in aphid bearing period			0.006	0.027
Standard deviation of average temperature in aphid bearing period			0.331***	0.117
Precipitation amount at different growth stages of cotton aphids				
Average precipitation in autumn spawning period	-0.003***	0.001	-0.003	0.004
Quadratic component of average precipitation in autumn spawning period			-0.000	0.000
Standard deviation of average precipitation in autumn spawning period			0.003	0.003
Average precipitation in wintering period	0.006**	0.002	-0.004	0.006
Quadratic component of average precipitation in wintering period			-0.000	0.000
Standard deviation of average precipitation in wintering period			0.032***	0.011
Average precipitation in incubation and migration period	-0.005***	0.002	-0.011*	0.006
Quadratic component of average precipitation in incubation and migration period			0.000	0.000
Standard deviation of average precipitation in incubation and migration period			0.002	0.006
Average precipitation in seedling aphid period	-0.002**	0.001	-0.004	0.003
Quadratic component of average precipitation in seedling aphid g period			0.000	0.000
Standard deviation of average precipitation in seedling aphid period			-0.006	0.004
Average precipitation in aphid bearing period	-0.001***	0.000	0.002	0.002
Quadratic component of average precipitation in aphid bearing period			-0.000	0.000
Standard deviation of average precipitation in aphid bearing period			0.004	0.003
Occurrence degree of cotton aphids in the previous year	0.476***	0.084	0.452***	0.082
Proportion of the sown area of transgenic insect-resistant cotton	-0.541***	0.146	-0.386**	0.192
Proportion of effective irrigation area in cultivated land area	-0.551**	0.218	-0.513**	0.204
Chemical fertilization rate per hectare//t/h	-0.039	0.348	-0.027	0.356
Crop planting structure (proportion of sown area)				
Cotton	1.948*	1.005	1.345	1.027
Wheat	-0.740	0.579	-1.089*	0.584
Rice	-3.066	4.965	-3.612	5.368
Corn	1.749***	0.628	2.033***	0.682
Number of samples	627		627	

* * *, * *, and * indicate significant difference of the statistical estimation coefficients at the level of 0.01, 0.05 and 0.1, respectively.

Huang-Huai-Hai River Basin, while the changes were only in significant linear relationship with the growth of cotton aphid in the Yangtze River Basin. The estimation results of the model for the Huang-Huai-Hai River Basin showed that the one degree term and quadratic term coefficients of temperature were negative and positive, respectively, and both were significant (Table 4). Further analysis showed that the occurrence of cotton aphid would be-

Table 5 Estimation results of econometric model of determinants of occurrence degree of cotton aphid in the Yangtze River Basin

	Model 1		Model 2	
	Coefficient	Standard error	Coefficient	Standard error
Temperature at different growth stages of cotton aphids				
Average temperature in autumn spawning period	−0.422***	0.162	2.162	3.373
Quadratic component of average temperature in autumn spawning period			−0.063	0.080
Standard deviation of average temperature in autumn spawning period			0.143	0.118
Average temperature in wintering period	0.111	0.108	0.371	0.696
Quadratic component of average temperature in wintering period			−0.018	0.046
Standard deviation of average temperature in wintering period			0.091	0.119
Average temperature in incubation and migration period	−0.004	0.096	1.027	0.788
Quadratic component of average temperature in incubation and migration period			−0.043	0.031
Standard deviation of average temperature in incubation and migration period			−0.067	0.075
Average temperature in seedling aphid period	0.226**	0.111	2.550	2.953
Quadratic component of average temperature in seedling aphid period			−0.048	0.063
Standard deviation of average temperature in seedling aphid period			−0.037	0.154
Average temperature in aphid bearing period	−0.037	0.091	−5.718*	3.045
Quadratic component of average temperature in aphid bearing period			0.103*	0.056
Standard deviation of average temperature in aphid bearing period			0.624***	0.196
Precipitation amount at different growth stages of cotton aphids				
Average precipitation in autumn spawning period	0.000	0.001	−0.000	0.004
Quadratic component of average precipitation in autumn spawning period			−0.000	0.000
Standard deviation of average precipitation in autumn spawning period			0.016***	0.005
Average precipitation in wintering period	−0.000	0.001	0.001	0.005
Quadratic component of average precipitation in wintering period			−0.000	0.000
Standard deviation of average precipitation in wintering period			0.009	0.009
Average precipitation in incubation and migration period	0.001	0.001	−0.002	0.004
Quadratic component of average precipitation in incubation and migration period			0.000	0.000
Standard deviation of average precipitation in incubation and migration period			−0.006	0.004
Average precipitation in seedling aphid period	0.001	0.001	0.006***	0.001
Quadratic component of average precipitation in seedling aphid g period			−0.000***	0.000
Standard deviation of average precipitation in seedling aphid period			−0.003	0.002
Average precipitation in aphid bearing period	−0.001**	0.000	0.003	0.002
Quadratic component of average precipitation in aphid bearing period			−6.74e−06**	0.000
Standard deviation of average precipitation in aphid bearing period			0.005**	0.002
Occurrence degree of cotton aphids in the previous year	0.625***	0.110	0.642***	0.119
Proportion of the sown area of transgenic insect-resistant cotton	−0.241	0.227	−0.508*	0.262
Proportion of effective irrigation area in cultivated land area	−0.550**	0.224	−0.724**	0.290
Chemical fertilization rate per hectare//t/h	0.999***	0.388	1.691***	0.539
Crop planting structure (proportion of sown area)				
Cotton	−0.406	2.397	−0.370	2.737
Wheat	−0.907	1.543	−0.229	1.759
Rice	−0.847	0.793	−1.426*	0.867
Corn	1.811	2.936	1.698	3.065
Number of samples	323		323	

* * *, * *, and * indicate significant difference of the statistical estimation coefficients at the level of 0.01, 0.05 and 0.1, respectively.

come heavier when the temperature was over 22.6 ℃, and the occurrence would be inhibited if the temperature was below 22.6 ℃, indicating that during the seedling aphid period, cotton aphid was fond of low temperature in the Huang-Huai-Hai River Basin. In addition, large fluctuation of average temperature during the seedling aphid period was not conductive to the growth and development of cotton aphid. However, in terms of the Yangtze River Basin, the estimated coefficients of temperature were positive and significant in the linear model, but were not significant in the nonlinear model (Table 7). It indicated that the rising of temperature in the seedling aphid temperature was favorable for the growth of cotton aphid in the Yangtze River Basin, but there was no transitional problems.

The growth of cotton aphid in the Yangtze River Basin was more sensitive to the temperature in the aphid bearing period, presenting significant nonlinear correlation, while there was only linear correlation in the Huang-Huai-Hai River Basin (Table 4 and 5). The estimation results of the model for the Yangtze River Basin showed that the one degree and quadratic terms of temperature were all significant, with a negative sign and a positive sign, respectively, and the standard deviation was also positive significant. Further analysis showed that the transitional point of the temperature during the aphid bearing period in the Yangtze River Basin was 28 ℃, which indicated that there would be no cotton aphid occurrence when the temperature was below 28 ℃. The average temperature during the aphid bearing period in the Yangtze River Basin was 26 ℃, suggesting that the occurrence degree of cotton aphid would not increase even the temperature increased by 2 ℃ more, but if the temperature increased by more than 2 ℃, the occurrence degree of cotton aphid would become heavier. In the Huang-Huai-Hai River Basin, the temperature during the aphid bearing period presented significant negative correlation with the occurrence of cotton aphid, indicating that the further temperature rising was not favorable for the growth of cotton aphid. In addition, both in the Yangtze River Basin and in the Huang-Huai-Hai River Basin, a larger fluctuation of average temperature during the aphid bearing period was more favorable for the growth and development of cotton aphid.

Impact of precipitation on the occurrence degree of cotton aphids in different growth stage

In the Huang-Huai-Hai River Basin, the occurrence of cotton aphid would decrease significantly if the precipitation during the 4 growth stages (autumn spawning period, incubation and migration period, seedling aphid period and aphid bearing period) increased (Table 4). The precipitation in the 4 growth stages was linear negatively significant in the model for the Huang-Huai-Hai River Basin, and neither the nonlinear variables nor the standard deviation was significant, indicating that when the other factors were the same, the increase of precipitation during the 4 growth stage could significantly inhibit the occurrence of cotton aphid. However, only the precipitation in the wintering period showed positive linear correlation with the occurrence of cotton aphid, and the standard deviation of wintering period was also positively significant, indicating that the increase of precipitation or the fluctuation of precipitation during the wintering period was favorable for the growth of cotton aphid.

Different from that in the Huang-Huai-Hai River Basin, the growth of cotton aphid in the Yangtze River Basin was mainly sensitive to the precipitation in the seedling aphid and aphid bearing period, and had response to the precipitation fluctuation in the wintering period, while there was no significant correlation with the precipitation in the other 2 growth stages (autumn spawning period and incubation and migration period) (Table 5). In the model for the Yangtze River Basin, the one degree term of precipitation in the seedling aphid period was positively significant, while the quadratic term was negative significant. Further analysis showed that if the precipitation did not go beyond the transitional point of 506 mm, the increase of precipitation was conductive to the occurrence of cotton aphid; otherwise, the further increase of precipitation would inhibit the occurrence of cotton aphid. The precipitation in the aphid bearing period was also present similar correlation with the occurrence of cotton aphid, and the quadratic term was negative significant, and standard deviation was positive significant. Therefore, the further increase of precipitation in the aphid bearing period would inhibit the occurrence of cotton aphid, but the fluctuation of precipitation was conductive to the growth of cotton aphid.

Impact of social and economic factors on the occurrence degree of cotton aphids

In addition to climate change, Occurrence degree of cotton aphids in the previous period, Proportion of the sown area of transgenic insect-resistant cotton, Effective irrigation area and Crop planting structure also had a significant effect on the occurrence degree of cotton aphid (Table 4 and Table 5). The estimation results of the models for the Huang-Huai-Hai River Basin and the Yangtze River Basin showed that in both models, the estimated results of the variable Occurrence degree of cotton aphids in the previous period was positive and significant at the level of 1%. It suggested that the occurrence degree of cotton aphids in the previous year was in significant positive correlation with the occurrence degree in the current years, indicating that the occurrence of cotton aphids had some sensitive or suitable regions. The 4 model estimation results of the Proportion of sown area of transgenic insect-resistant cotton in the 2 regions were all negative, and the statistical test was significant in the 2 models for the Huang-Huai-Hai River Basin and the nonlinear model for the Yangtze River Basin, indicating that the popularization of transgenic insect-resistant cotton indirectly inhibited the occurrence of cotton aphid in the Huang-Huai-Hai River. However, further analysis was needed to find out the inhibitory effect in the Yangtze River Basin. In addition, in the model estimation results of the 2 regions, the estimation results of the Proportion of effective irrigation area in cultivated land area were all negative and significant at the level of 5%, indicating that the land had good irrigation conditions would have light occurrence of cotton aphid, that is, cotton aphids were fond of dry environment but not wet. The estimation results also showed that the occurrence of cotton aphid was also in a certain correlation with the crop planting structure. For example, in the Huang-Huai-Hai River, the proportion of corn sown area presented significantly positive correlation with the occurrence degree of cotton aphid, indicating that corn field was not favorable for the growth the natural enemies of cotton aphids, thereby providing good ecological environment for the growth of cotton aphids. In the Yangtze River Basin, the occurrence degree of cotton aphid would be light if the proportion of rice planting area was big. Finally, the study results also found that in the Yangtze River Basin, the occurrence degree of cotton aphid was in positive correlation with the application amount of chemical fertilizers, that is, a high amount of applied chemical fertilizers was unfavorable for the occurrence of cotton aphids. However, the estimation results in the Huang-Huai-Hai River showed no significant correlation between the application of chemical fertilizers and the occurrence degree of cotton aphids.

Conclusion

In this study, econometric models were established to explore the impacts of climate change on the occurrence degree of cotton aphids based on the observation data from 50 counties in the Huang-Huai-Hai and Yangtze River basins in 1991–2010, including variables on the occurrence degree of cotton aphids, temperature and precipitation, and other socio-economic factors. And the results showed that there were significant differences in the effects of temperature and precipitation changes on the occurrence degrees of cotton aphid in different growth stages, and even in the same growth stage, the cotton aphids had different responses to the changes of temperature and precipitation in different regions. Temperature increase in the wintering period and seedling aphid period was conductive to the growth of cotton aphid in the the Huang-Huai-Hai River Basin, while the temperature increase in the autumn spawning period and aphid bearing period would inhibit the occurrence of cotton aphid in the region. As for the Yangtze River Basin, a high temperature in the seedling aphid period and aphid bearing period was favorable for the occurrence of cotton aphid, while the increase of temperature in the autumn spawning period would inhibit the occurrence of cotton aphid. The fluctuation of temperature in the aphid bearing period and incubation and migration period was conductive to the occurrence of cotton aphids.

In the Huang-Huai-Hai River Basin, the increase of precipitation in most of the growth stages of cotton aphids (autumn spawning, incubation and migration, seedling aphid and aphid bearing periods) would inhibit the occurrence of cotton aphid, while in the Yangtze River Basin, the increase of precipitation in seedling aphid period and aphid bearing period would have significant inhibitory effects on the occurrence of cotton aphids. The results showed that it should give full consideration to the climatic conditions in different periods of different regions, and it should adopt proper measures to control the cotton aphids on the basis of figuring out the occurrence rule of cotton aphid, so as to ensure cotton production. Finally, in addition to climate change, the prevention and control of cotton aphids should pay full attention to the indirect inhibition of transgenic insect-resistant cotton, and make full use of the rational distribution of irrigation conditions, fertilization levels and planting structure to achieve effective results.

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850 hPa, and the invasion of weak cold air at 700 hPa triggered severe convection weather.

(2) There was certain water vapor transport and convergence before the occurrence of severe convection, and it was warm and wet at low altitudes but dry and cold at high altitudes; there was convergence at low altitudes and divergence at middle and high altitudes, which are the important conditions for the occurrence and development of the two times of severe convection. 0 ℃ layer was at about 4 000 m, and -20 ℃ layer was at about 7 000 m.

(3) Radar echo intensity was larger than 45 dBZ when severe convection happened, and it reached above 60 dBZ at an elevation of 1.5°, while middle strong echo zone overhung weak echo zone at low altitudes. VIL was up to 20 kg/m^2, and mesocyclone generated in strong echo zone; there was bow echo on the night of June 13, and VIL was higher than that on June 14. In wind profiler data, strong vertical wind shear and fluctuation of wind direction had denotative meaning to the occurrence of severe convection weather.

(4) Hail, gale and other severe convection weather happened in front of long and narrow cold cloud zone and convective cloud clusters as well as in southwestern TBB gradient zone.

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Responsible editor: Yingying YANG Responsible proofreader: Xiaoyan WU

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Responsible editor: Na LI Responsible proofreader: Xiaoyan WU