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CONTRIBUTION OF CLIMATE WARMING TO THE INCREASED YIELD OVER THE PAST TWO DECADES:

A CASE STUDY OF RICE CROPS IN HEILONGJIANG PROVINCE, NORTHEAST CHINA

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ABSTRACT: Studying the impact of the existing climate warming to crop yield is an effective approach for understanding the impacts of climate change on agriculture. However, it is difficult to separate the contribution of climate change and human activities in such a study. Traditionally, the real yield is separated into trend yield that fits the real crop yield by a trend line dependant on time only; and the fluctuant yield which is the residual yield between the real yield and the trend. The fluctuant yield is regarded as the climatic yield. The main disadvantage of the traditional method is that it could not show the contribution of a climatic trend to the yield trend. In this paper, a new method, which may overcome the disadvantage of the traditional method, is put forward to calculate a climate yield with a climate trend. In the new method, a referenced period that satisfies the hypothesis of the traditional method is selected to construct a function on the dominant meteorological factor and climate influence coefficient by regression. The function can be used to calculate the climate's influence coefficient of other years. Rice yield in Heilongjiang province is restricted mainly by temperature. A case study on the contribution of climate change to rice yield change from 1952 to 2000 is made in this region. The results show that, although non-climatic forces have likely dominated the trends in rice per unit area yield in Heilongjiang province, the impact of climate warming on rice production becomes more and more prominent during the past 20 years. The real rice yield per unit area in the 1980s is 30.6 percent higher than that in the 1970s. The increased yield due to a warming climate was from about 12.8 to 16.1 percent of the real increased yield. The real rice yield per unit area in the 1990s is 42.7 percent higher than that in the 1980s. The increased yield due to warming climate was about 23.2 to 28.8 percent of the real increased yield.

Keywords: climate change; agriculture; rice; China

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC) report, the average global surface temperature has increased by 0.6±0.2 degrees Celsius since the late 19th century (IPCC, 2000). Global change as signaled by global warming has become a reality that human beings have to face. Among many aspects impacted by the climate change, agriculture is one of the most sensitive. Current conclusions about the impacts of global warming on agriculture was drawn mainly from the results of models under a given climatic scenario. According to the IPCC (2000) report, agricultural production in the mid-latitude regions will be positive if the temperature rises within a few degrees. Beyond this range, the impacts will be negative (Zhang Qingyang et al., 2001). In China, the simulated results of a future climate show that by the year 2050, almost all the planting systems would be significantly changed due to the climate warming. The multi-cropping index will increase, and the cropping pattern will be diversified. Yet the imbalance between precipitation and evaporation, the thirsty demand for water by the land, and the shortening of the growing season will eventually lead to the reduction of main crop yields in China (Wang Futang, 2002).

On the other hand, the last two decades were the warmest period of the 20th Century (IPCC, 2000). It is an effective way for understanding the impact of global warming on agriculture by linking the warming to the agricultural production during this period. Yet the research is difficult to carry out because contrary opinions exist with regard to the integrated effects of climate change and the advancement in technology. Recently, Lobell and Asner (2003) estimated the effect of climate change on the yield of maize and soybean in the USA since the 1980s, but their research methods were questioned immediately (Gu Lianhong, 2003). J. Reilly et al. (2003) studied the impacts of climate change on American agriculture and showed that these impacts might be often overshadowed by other factors. Therefore, it is quite difficult to identify out the climate impact based on the historical statistical data. It is necessary to assume that the technological conditions should be the same at any given time in order to prove the impacts of climate change on agricultural production (J. Reilly et al., 2003). Undoubtedly, there are different opinions on how to evaluate the contribution of climate change and technology to agricultural production. The argument also implies the necessity to distinguish the two, especially when technology is developing fast while the world is getting warmer and warmer.

Heilongjiang Province is located in the most northern part of China. It is one of the areas most sensitive climate change in China, and it has experienced significant climate warming over the past 20 years (Sha Wanying et al., 2002). The crop structure in the province is restricted mainly by the temperature and sensitivity to temperature change. In the past twenty years, the crop structure and total yield in Heilongjiang has undergone dramatic changes. Rice has become a major crop in this region, whose plantation area is only smaller than that of soybean and maize, and total yield is the largest of all (Jiao Jiang, 2002). Generally, rice requires warmer temperature for growth and is more sensitive to climate change than other crops such as wheat and maize in Heilongjiang Province. The temperature during the growth season in Heilongjiang Province is near the lower temperature limit for the optimal growth of rice (Chinese Planting Administration, 2002). This paper aims to quantitatively estimate the contribution of climate warming to the increased yield in the condition of fast development of agricultural technology through a case study in Heilongjiang Province. For this purpose, a new method is developed to estimate the contribution of climate warming on the increase of rice yield in Heilongjiang Province.

2. Data and Methods

The climate data used in this paper are air temperature and precipitation data at 22 weather stations in Heilongjiang Province from 1952 to 2000. The selected stations represent the climate conditions of the total planting area of rice, because among them, 20 stations are located in regions having rice planting; with 14 stations located in regions having a large area for rice planting (see Figure 1). The data of the rice yield per unit area from 1952 to 2000, come from the *Economic Statistic Year book in Heilongjiang Province* (1988-2001) (Heilongjiang Provincial Statistic Bureau, 2001).

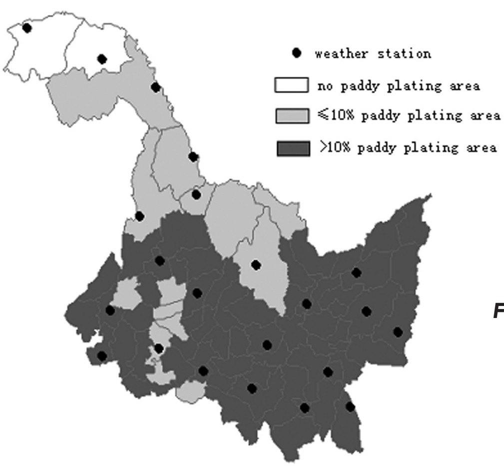

FIGURE 1

Weather stations and percentage of paddy area to the total planting area of wheat, maize and rice in 2000 in Heilongjiang Province

2.1 Temperature sequence in growth season

Growth of the crops in Heilongjiang is associated primarily with the climate conditions during the growth season from May to September (Sun Yuting et al., 1986). According to the data from 22 climate stations, the precipitation and the accumulated average monthly temperature for May-to-September of each year from 1952 to 2000 are calculated. Using the precipitation (R_{5-9}) and the accumulated monthly average temperature (T_{5-9}) from 1961 to 1990 as standards, the anomaly of precipitation ($\triangle R_{5-9}$) and the anomaly of accumulated average temperature ($\triangle T_{5-9}$) for May to September are calculated (see Figure 2).

Statistical analysis software, SPSS, was used to test the differences in the statistical significance for the temperature of May-to-September among the 1970s, 1980s, and 1990s.

2.2 Calculation of climate impact coefficient

How to separate the rice yield determined by climate change from the total rice yield is the key in evaluating the influence of climate change. Traditionally, the real yield is separated into trend yield that fits the real crop yield by a trend line depended on time only, and the fluctuant yield which is

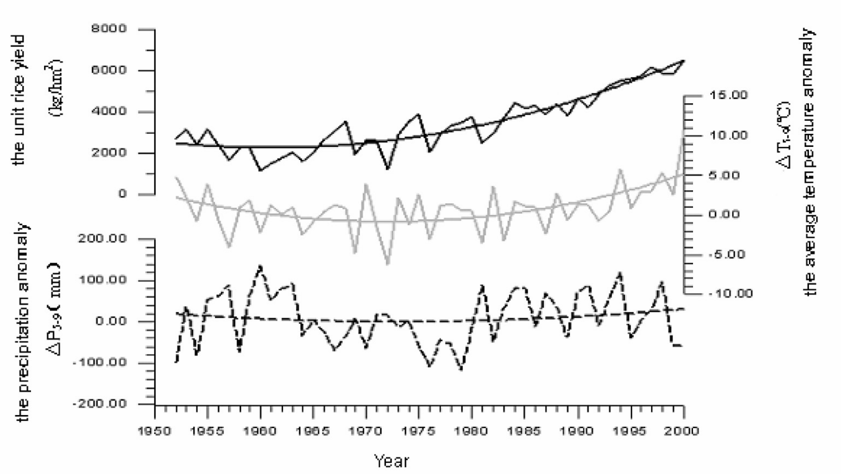

FIGURE 2

Changes of the temperature, precipitation and the rice yield per unit area for 1952-2000 in Heilongjiang Province.

the residual yield between the real yield and the trend. The trend yield is regarded to reflect the growth of productivity in history and the fluctuant yield is regarded as the climatic yield. (Wang Futang, 1991)

$$Y = Y_t + Y_w + e \qquad (1)$$

In formula (1), Y is cereal crop yield per unit area (kg/hm^2); Y_t represents the trend yield (kg/hm^2); Y_w stands for fluctuant yield; and e is the yield caused by random factors which are often ignored in calculation.

Based on the above, the functions of a cubic polynomial, exponential function, and 5-year running mean are used to fit the trend yield and to separate the climatic rice yield per unit area from 1952 to 2000 in Heilongjiang Province. Despite differences, all the results show that before the 1980s, the climatic yield of rice had significant correlation with temperature and less dependence on precipitation. After the 1980s, the dependence on precipitation remained insignificant, but the correlation between climatic yield and temperature decreased (see Table 1). Moreover, in the 1990s, the fluctuation of the climate yield further decreased, resulting in less correlation to temperature. Such a result might lead to a conclusion that the climate impact on rice production decreases as the temperature increases. In fact, it is a misunderstanding. The problem lies in the hypothesis that climate is assumed to be a steady sequence without tendency, but not all the periods accord with it. The climate factors may also have long-term tendency, which impacts on crop production too. The trend yield fitted based on the Formula (1) often includes the climatic yield contributed by the long-term climate trend without the technological factors. It is unavoidable to make errors when

Table 1 Correlation coefficients between climatic yields fitted by different regression and temperature and precipitation in Heilongjiang Province

PERIOD	CLIMATIC FACTORS	Y1W (EXPONENTIAL FUNCTION)	Y2W (CUBIC POLYNOMIAL)	Y3W (5-YEAR RUNNING MEAN)
1961-1980	T	0.667*	0.621*	0.636*
	P	-0.247	-0.297	-0.144
1981-2000	T	0.582*	0.394	0.307
	P	-0.045	0.076	0.119

Note: *significance level is 0.01, T is the anomaly of accumulative average temperature ($\triangle T_{5\text{-}9}$), R is the anomaly of precipitation ($\triangle R_{5\text{-}9}$).

analyzing the relation between crop yield and climate change. In the case of the trend yield of rice in Heilongjiang Province fitted above contains not only the contribution by the advancement in technological measures, but also the contribution by the climate warming. That is the deficiency of the method above.

In order to overcome the deficiency of the traditional method, a modified method is presented, that is, to select a reference period and to establish a function by regression on the relation between rice yield per unit area and temperature within the referenced period, then to estimate the contribution of temperature change to the rice yield per unit area beyond the reference period (Wang Yuan et al., 2004). The so-called reference period must simultaneously satisfy the following three conditions. First, the temperature change during this period has little long-term trend, with permissible short-term fluctuations; and the fluctuant yield is highly and steadily correlated to temperature change. Second, technological development exerts a gradual impact on the yield during the period, instead of an abrupt impact by sudden or rapid technological innovation. Third, the yield change caused by expansion of rice-planting area is ignored. In such a defined referenced period, Formula (1) can practically work. In another words, the trend yield obtained by regression reflects the influence of human activities, while the fluctuant yield represents mainly climatic influence during the referenced period.

Crop yield per unit area is surely varied under different technological conditions, as well as the contribution of temperature change to total crop yield. The contribution of climate to the crop yield per unit area is described by the temperature impact coefficient expressed below.

$$\alpha = Y_w / Y_t \qquad (2)$$

In formula (2), α is the temperature impact coefficient, which may be calculated according to the relationship between the temperature and the climatic yield separated from real rice yield during the referenced period. To imitate the temperature effect function in the crop potential productivity formula, a quadratic function is employed to estimate the temperature impact coefficient α.

$$\alpha(T) = aT^2 + bT + c \qquad (3)$$

In equation (3), T is the anomaly of accumulative average temperature ($\triangle T_{5-9}$) from May to September. a, b, and c are the coefficients which may be calculated by using non-linear regression in SPSS software. The temperature impact coefficient calculated from the above regression equation could reflect the sensitivity of unit crop yield to climate change under the technological conditions in the referenced period. The higher the climatic influence coefficient gets, the more sensitive the unit crop yield responds to the temperature change.

2.3 Estimation of the contribution of climate warming to the increased unit rice yield

From the equations (1) and (2), the climatic yield and the technological unit yield could be deduced as equations (4) and (5) respectively.

$$Y_w = \alpha Y_t = \frac{\alpha Y}{1 + \alpha} \tag{4}$$

$$Y_t = \frac{Y}{1 + \alpha} \tag{5}$$

The contribution of climate warming to the increased rice yield per unit *(W)* can be expressed by the ratio of an increase in the climatic yield (the climatic yield after climate warming minus that before climate warming) to the increase in the real yield (the real yield after climate warming minus that before climate warming).

$$W = \frac{Y_{w(n)} - Y_{w(i)}}{Y_n - Y_i} \times 100\% \tag{6}$$

In equation (6), $Y_{w(n)}$ and Y_n represent the climate yield and the real yield in the *n*th period when after climate becomes warming, respectively; and $Y_{w(i)}$ and Y_i represent the climatic yield and the real yield in the *i*th period before the *n*th period, respectively.

3. Results

3.1 Climate Change from May to September in Heilongjiang Province

The climate in Heilongjiang Province has been getting warmer since the 1980s. The temperature change since the 1980s could be divided into three periods separated by 1987 and 1993. The anomaly of accumulative average monthly temperature from May to September in these three periods, were 0.20 degrees Celsius, 0.36 degrees Celsius and 4.48 degrees Celsius higher than that in the 1970s, respectively. The significant warming has occurred since 1994 (Figure 2).

On the decadal scale, the climate warming started from the 1980s, but the warming in the 1980s was limited, which had not exceeded the amplitude of temperature fluctuation during the 1960s and the 1970s, although the extreme low temperature like in 1969, 1972, and 1976 did not occur again in the 1980s (see Figure 2). The warming in the 1990s was remarkable. The anomaly of accumulative average monthly temperature from May to September in 1990 was 3.58 degrees Celsius higher than that in the 1970s. In other words, the monthly average temperature increased 0.72 degrees Celsius during May-September in the 1990s. The temperature in the colder years in the 1990s was similar to that of warmer years during the 30 years before the 1990s.

3.2 The impact of temperature change on rice yield per unit area in Heilongjiang Province

Rice is one of the crops sensitive to temperature change. The suitable temperature required by different rice varieties is varied. The mean temperature during the growth season from 1981 to 2000 in Heilongjiang Province (not including the Daxing'anling Mountains region) was below the optimal mean temperature demanded by the dominant rice varieties planted in Heilongjiang Province, while the maximum temperature was around the optimal maximum temperature *(Chinese Planting Administration, 2002; Liang Guangshang, 1983; Chinese Institute of Rice et al., 1988).* This means that the climate warming since the 1980s acted as a positive impact on rice growth and yield because the warming has not exceeded the optimum temperature limit in the majority areas of Heilongjiang Province.

The temperature impact coefficient α is the index that quantitatively reflects the impact of temperature on the crop yield per unit area. In order to establish the regression equation between the temperature and the temperature impact coefficient α from the statistic data in Heilongjiang Province, the referenced periods that satisfied the standards as described above were identified. Abrupt increases in the rice yield per unit area occurred around the years 1965, 1983, and 1992 (see Figure 2), which divided the changes of the rice yield per unit area into four periods of 1952-1964, 1965-1981, 1983-1991, and 1992-2000. The fluctuant yield and trend yield were separated by fitting the trend with linear equation in each of the four periods. The coefficient between the temperature and the α (the percentage of rice fluctuant yield to the trend yield) is 0.51 for 1952-1964, 0.75 for 1965-1981, 0.79 for 1984-1991, and 0.32 for 1992-2000, respectively. 1965-1981 and 1984-1991 are selected to be the referenced periods because the temperature exhibited fluctuations without obvious long-term trends and the coefficient between temperature and fluctuant yield were high enough during these two periods (see Figure 3).

Based on formula (3), a quadratic function is drawn for the temperature impact coefficient α during the two referenced periods (equation (7) for 1965-1981, and equation (8) for 1984-1991) respectively, (see Figure 4). Whereas the

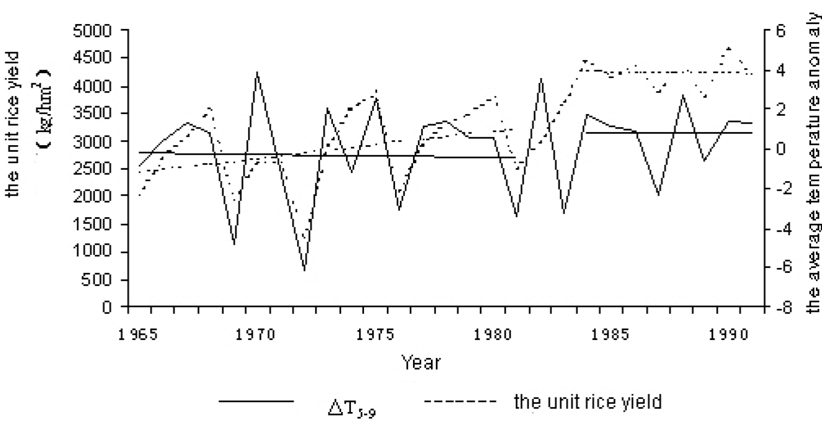

FIGURE 3

Changes in temperature and rice yield per unit area for two referenced periods in Heilongjiang Province samples in the period of 1984-1991 were a little bit small in numbers, the symmetry axis for the equation (7) during 1965-1981 is employed by the equation (8) on the assumption that the optimum temperature for rice growth did not change.

$$\alpha_1(T) = -0.001897T^2 + 0.074306T + 0.023026 \qquad R^2=0.67 \quad (7)$$

$$\alpha_2(T) = -0.000894T^2 + 0.034999T + 0.025456 \qquad R^2=0.65 \quad (8)$$

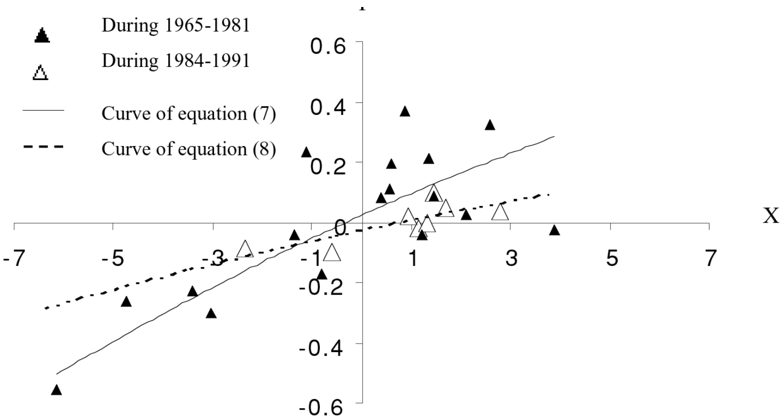

FIGURE 4

Relationship between temperature and impact coefficient of temperature for 1965-1981 and 1984-1991.(Y axis shows temperature impact coefficient, X axis shows temperature during May to September (degrees Celsius))

The temperature impact coefficients obtained from equations (7) and (8) represent the relative sensitivity of rice yield per unit area to climate change in Heilongjiang Province under the two different technological conditions during 1965-1981 and 1984-1991 respectively. To compare the equations (7) and (8), it is found that the advancement in technology did not only increase the rice yield per unit area, but also reduced the sensitivity of the rice yield per unit area to temperature change which is shown by the decreased percentage of climatic yield out of the total yield under a similar amplitude of temperature change.

3.3 Contribution of the decadal climate warming to the increased rice yield per unit area in Heilongjiang Province

According to the equation (2), the change of rice yield per unit area results from the combined impacts by both technological renovation and climate warming. It is hard to completely separate the two factors. On one hand, advancement in technology increases the rice yield per unit area, as well as reduces the sensitivity of rice growth to temperature changes. On the other hand, the climate warming allows the introduction of rice variety with high yield. The impact of climate warming on rice yield per unit area in the past two decades in Heilongjiang Province occurred under the fast changes in technological conditions. Thus, the technological change needs to be given a full consideration when calculating the contribution of climate warming to the increased yield. The temperature impact coefficient is calculated from the function that is established in the referenced period. It is reasonable to use the decadal average temperature to calculate the decadal temperature impact coefficient approximately, because the temperature impact coefficient calculated from the anomaly of decadal accumulated average monthly temperature during May-September is not much different from that on a year-to-year basis of the 10 years.

The average rice yield per unit area in the 1980s was about 4000kg/hm^2 which is about 30.6 percent higher than that in the 1970s. Such an increase occurred mainly around 1983, when the rice yield per unit area jumped from 3000 kg/hm^2 to 4000 kg/hm^2. After this abrupt rise, the rice yield per unit area fluctuated around 4000 kg/hm^2 depending on the rise or fall of the temperature (Figure 2). The dry and thin rice planting, which was being widely applied in Heilongjiang Province around 1983, was the dominant reason for the large-scale increase in rice production in the 1980s. Such a technique may increase the rice yield per unit area by 10 to 20 percent (Zheng Hua et al., 1999), which equals about 32.1 to 65.4 percent of the increased yield.

Another important reason for the increase in the rice yield per unit area is the agricultural policy since the 1980s that aroused the farmers' enthusiasm for production. Although the air temperature rise in the 1980s was not significantly different from that of the 1970s in statistics, the contribution of climate warming to the increase in rice yield per unit area cannot be ignored. With the assumption that the sensitivity of the rice yield to temperature change is maintained as in 1965-1981, the reference period of 1965-1981 may be used for estimating the contribution of climate warming to the increase of the rice yield per unit area in the 1980s. If the technological yield did not change, the increased yield brought by climate warming accounted for 12.8 percent of the total increased yield per unit area from the 1970s to the 1980s. If the technological yield increased gradually with the trend as that in 1965-1981, the contribution by climate warming would be 16.1 percent of the increased yield. That is, the contribution of the climate warming to the increased yield per unit area is 12.8-16.1 percent in the 1980s (see Table 2).

Table 2 Contribution of climate warming to the increased rice yield during past two decades in Heilongjiang Province

DURATION	1971-1980	1981-1990	1991-2000
Anomaly of temperature ($T_{5\text{-}9}$, referenced to 1961-1990)	-0.316	0.210	3.260
Average yield per unit area` (kg/hm^2)	2985	3897	5561
Increased yield than the former decade (kg/hm^2)	n/a	912	1664
Part of increased yield per unit area for climate warming than the former decade (kg/hm^2)	n/a	117~147	386~480
Contribution of the climate warming to the increased yield per unit area than the former decade	n/a	12.8-16.1	23.2~28.8

As compared to that of the 1980s, the climate warming in the 1990s underwent a significant change. However, the impact on the yield per unit area by technological advancement was also enhanced. For example, the temperature in 1995 was similar to that of 1986 with little difference in other climate conditions, but there was a difference of 1272 kg/hm^2 in the rice yield per unit area. Such a change was likely the result of technological change. The technological advancement also lowers the sensitivity of rice growth to climate warming. Therefore, it is probably more practical to estimate the contribution of the climate warming to the increased rice yield per unit area in the 1990s, based on the temperature sensitivity of the rice yield per unit area in the reference period of 1984-1991 than that in 1965-1981. If the technological yield did not change, the increased yield brought by climate warming accounted for 23.2 percent of the total increased yield per unit area from the 1980s to the 1990s. If the technological yield increased gradually with the trend as that in 1984-1991, the contribution by climate warming would be 28.8 percent of the increased yield. That is, the contribution of the climate warming to the increased yield per unit area is about 23.2 to 28.8

percent from the 1980s to the 1990s. It means an increase of about 9.9 to 12.3 percent in rice yield per unit area by climate warming in the 1990s, as compared to that of the 1980s. So, the impact of climate warming on rice yield in the 1990s is stronger than that in the 1980s.

In sum, the unit rice yield increased 2575 kg/hm^2 from the 1970s to the 1990s, in which the total increased yield for climate warming was 503-627 kg/hm^2. Thus, the contribution of the climate warming to the total increased yield per unit area is between 19.5-24.3 percent.

4. Conclusions

From the analysis above, it is concluded that:

1. From the 1970s to the 1990s, the accumulated average monthly temperature during the growth season in May-September increased 3.58 degrees Celsius, being equivalent to an increase of 0.72 degrees Celsius for each month during May-September in Heilongjiang Province. The climate warming largely occurred in the 1990s.
2. The climate warming increased the rice yield per unit area in Heilongjiang Province. The contribution of climate warming to the increased rice yield per unit area in Heilongjiang Province is estimated in this paper. The rice yield per unit area increased 30.6 percent in the 1980s from that in the 1970s. About 12.8 to 16.1 percent was contributed by climate warming in the total increased yield. The rice yield per unit area increased 42.7 percent in the 1990s than that in the 1980s. About 23.2 to 28.8 percent was contributed by climate warming in the total increased yield. From the 1970s to the 1990s, the contribution of climate warming to the increased rice yield per unit area was estimated to be about 19.5 to 24.3 percent.
3. This case study provides a positive impact of climate warming in the past 20 years. It can be used to compare the climate impacts during different periods, and to compare the relative contribution (to food crop production) by natural and non-natural factors. It does not mean the results described in this study could be simply used for predicting the impact of further climate warming. The conclusion that the technological advancement lessens the impact of climate warming on the rice yield per unit area is drawn based on the climate warming conditions in the past 20 years. It remains to be examined whether such a conclusion is applicable under climate cooling conditions.

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