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CLIMATE CHANGE IMPACTS AND ADAPTATION: RICE PLANTATION IN NORTHEAST CHINA

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ABSTRACT: The average and standard deviation of the accumulated temperature from May to September for the period 1960-1999 of Northeast China is calculated. The result shows that the heat resource in almost all of Northeast China increased during this time period. According to the quantitative relation between heat resource and rice yield per-unit-area of different rice varieties of earliest ripe, early ripe, medium ripe, medium-late ripe and late ripe, a model is established to calculate the expected rice yield per-unit-area using the method of expectation evaluation of risk-benefit decision-making. It is found that climate warming induced positive effects on rice production in Heilongjiang and Jilin provinces of China, and induced negative effects in most areas of Liaoning Province, China. Changing crop varieties or crop structure to adapt to climate warming are two main adaptation activities. The crop structure of Northeast China changed in the past 20 years, and may reflect the regional differences of impact and adaptation activities. That is, rice yield per-unit-area in Heilongjiang and Jilin provinces increased more rapidly than that in Liaoning Province; the ratio of rice sown area to main grain (rice, wheat, maize) sown area in Heilongjiang Province increased more rapidly than that in Jilin Province, and the ratio decreased in Liaoning Province. So the impact of climate warming on crop yield and structure in China should not be ignored, though it is often credited to technology and economic benefit.

Keywords: adaptation; climate warming; expected yield per-unit-area; Northeast China;

1. Introduction

There is a consensus that climate has become warmer since the 1980s (IPCC, 2000). The socio-economic, political and environmental implications of this will be significant, especially for the agricultural system in China (Wadsworth and Swetnam, 1998). In some places climate change may produce positive effects on agriculture through introduction of new crop species and varieties, higher crop production and expansion of suitable areas for crop cultivation, whereas in some regions of China the disadvantages of climate change will predominate. The possible increase in the frequency of water shortages and extreme weather events may cause lower harvestable yields, higher yield variability and a reduction in suitable areas for traditional crops (Olesen and

Bindi, 2002). Many researchers have predicted the effect of future climate changes on crop production using a combination of field studies and models, but there has been little evidence relating decadal-scale climate change to large-scale crop production (Lobell and Asner, 2003). The aim of this research is to provide evidence of the impact of climate warming and relevant adaptation activities through a case study.

The research region is Northeast China located at 40 degrees North, and includes Heilongjiang Province, Jilin Province and Liaoning Province. The region is warm and wet in summer, and has a long, cold winter period. Soybean, corn, wheat and rice are the main crops planted in Northeast China. Northeast China supplies China with its main commodity grain base, but the region is short of heat resources. Cool summer hazards often hurt crops in the 1960's and 1970's in Northeast China (Zhang Yang-cai, 1991;Zu Shi-heng, 1999). Rice crops need higher temperatures than other grain crops, and are sensitive to climate warming. So the research on adaptation of rice to climate warming in the Northeast China would provide a regional example, and may be useful for proposing adaptation strategies to future climate warming.

2. Data and method

2.1 Data source

Agriculture data (1978-1999) were obtained from the Chinese Statistic Bureau including sown area and yield per-unit-area of grain (rice, wheat and corn). Meteorology data were obtained from the Chinese Meteorological Administration.

Temperatures between May and September are the main factor that impacts rice yields in Northeast China (Wang Shu-yu, 1980). The sum of average monthly temperatures between May and September ($T_{5\text{-}9}$) is calculated.

2.2 Method

Firstly, according to the relationship between extreme temperature and climate warming, the climate warming may change the probability of extreme temperature by changing the average or standard deviation of temperature. It is calculated that the average and standard deviation of the accumulated temperature between May and September ($T_{5\text{-}9}$) sequence of Northeast China.

In terms of the quantitative relation between heat resource and rice yield per-unit-area of different rice varieties of earliest ripe, early ripe, medium ripe, medium-late ripe and late ripe (Wang Shu-yu, 1980), a mathematical model was established to calculate the expected rice yield per-unit-area (Figure 1). There are a number of assumptions in this model: (a) Farmers are assumed to be rational, and economic people select dominating variety that has maximum expected yield to adapt the climate of the period; (b) Technology development is ignored; (c) and Water resources are enough for planting rice.

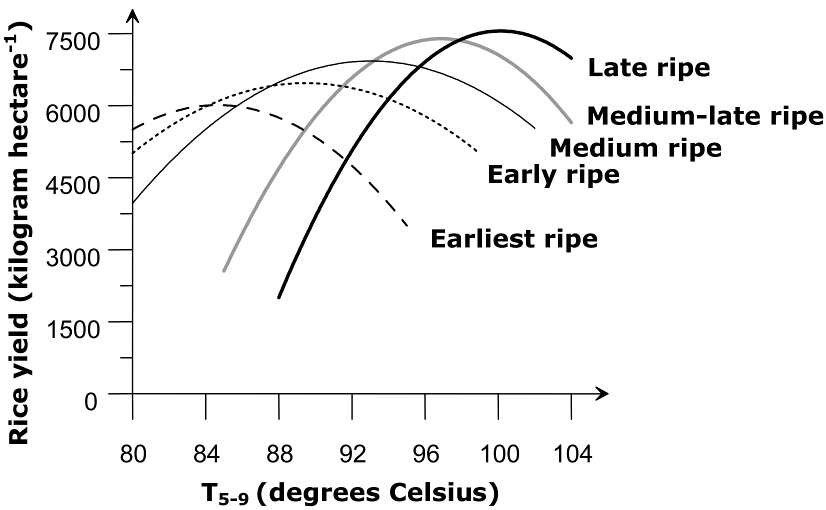


FIGURE 1

Relationship between rice yield per-unit-area of different varieties and T_{5-9} in the Northeast China (Wang Shu-yu, 1980). They may be fitted by quadratic polynomials approximately.

Late ripe: $y = -37.739x^2 + 7557.5x - 370810$;
Medium-late ripe: $y = -34.359x^2 + 6656.5x - 315006$
Medium ripe: $y = -17.421x^2 + 3241.6x - 143869$
Early ripe: $y = -16.231x^2 + 2904.9x - 123507$
Earliest ripe: $y = -23.485x^2 + 3976.5x - 162318$

For calculating expected yield per-unit-area, the reduced rate is defined as

$$x = 1 - \frac{Y(x)}{Y_{max}} \quad (1)$$

where x is the reduced rate, $Y_{(x)}$ is actual yield, and Y_{max} is the ideal maximum yield per-unit-area.

The formula used to calculate expected yield per-unit-area is as follows:

$$EY = \int_0^1 Y(x)p(x)dx \quad (2)$$

where EY is the expected yield per-unit-area; and *p(x)* is the probability density function of reduced rate, which can be derived by a relevant temperature probability density function. The following is the solution:

In terms of formula (1), actual yield per-unit-area is

$$Y(x) = Y_{\max} \cdot (1 - x) \quad (3)$$

Assuming the relationship between temperature and yield per-unit-area can be approximated to a quadratic polynomial (Figure 1), i.e.

$$Y(x(t)) = at^2 + bt + c \quad (4)$$

where t is $T_{5\text{-}9}$. In terms of formula (3) and (4), t is expressed as

$$t = \frac{-b \pm \sqrt{b^2 - 4ac + 4aY_{\max}(1 - x)}}{2a} \quad (5)$$

Temperatures obey approximate normal distribution, so its probability density function is

$$\varphi(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \quad (6)$$

where μ is average of $T_{5\text{-}9}$, and σ is standard deviation of $T_{5\text{-}9}$.

According to the relationship between temperature and the reduced rate, there is

$$F_1(x)=F_2(t) \tag{7}$$

where $F_1(x)$ is the probability distribution function of reduced rate x, $F_2(t)$ is the probability distribution function of $T_{5\text{-}9}$. In terms of the relationship between probability density function and probability distribution function, there is

$$p(x) = \varphi(t) \cdot \frac{dt}{dx} \tag{8}$$

So the probability density function $p(x)$ is

$$p(x) = [\varphi(\frac{-b+\sqrt{b^2-4ac+4aY_{\max}(1-x)}}{2a}) + \varphi(\frac{-b-\sqrt{b^2-4ac+4aY_{\max}(1-x)}}{2a})] \cdot \frac{Y_{\max}}{\sqrt{b^2-4ac+4aY_{\max}(1-x)}} \tag{9}$$

Finally, the actual rice sown area and yield per-unit-area were compared with the result of the model to analyze adaptation to climate warming.

2. Result

2.1 Heat resource and probability of extreme temperature

Since the $T_{5\text{-}9}$ increased notably in the 1990's, the cold period (1960-1979) is selected as the referenced period for the comparison to the warm period (1990-1999). Average and standard deviation of $T_{5\text{-}9}$ were calculated during these two time periods. There are comparative results as follows:

1. The average of $T_{5\text{-}9}$ increased in most of the stations in Northeast China. The accumulated temperatures of Jilin Province increased higher than that in the other two provinces (Table 1). The difference in average $T_{5\text{-}9}$ between the cold and warm periods is 3.09 degrees Celsius in Jilin Province, 2.57 degrees Celsius in Heilongjiang Province, and 1.89 degrees Celsius in Liaoning Province. The standard deviation of $T_{5\text{-}9}$ increased in

most of the stations in Jilin Province and Liaoning Province, however, decreased in most of the stations in Heilongjiang Province (Table 1).

Table 1 The average and standard deviation of accumulated temperatures (T_{5-9}) in Northeast China (degrees Celsius)

T_{5-9}	HEILONGJIANG		JILIN		LIAONING	
Period	1960-1979	1990-1999	1960-1979	1990-1999	1960-1979	1990-1999
Average	83.56	86.13	90.54	93.63	100.81	102.7
Standard deviation	2.52	2.05	2.79	3.15	2.46	2.87

2. Temperature (T_{5-9}) zones shifted northward and eastward, especially in Heilongjiang Province (Figure 2). The standard deviation of T_{5-9} decreased in northern areas (the region with positive) and increased in southern areas (the region with negative) (Figure 3).

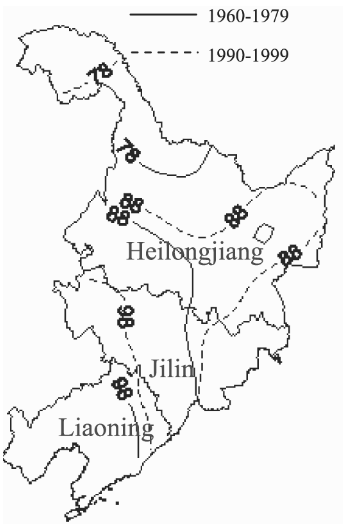


FIGURE 2

Isoline of average T_{5-9} (degrees Celsius) in Northeast China approximately.

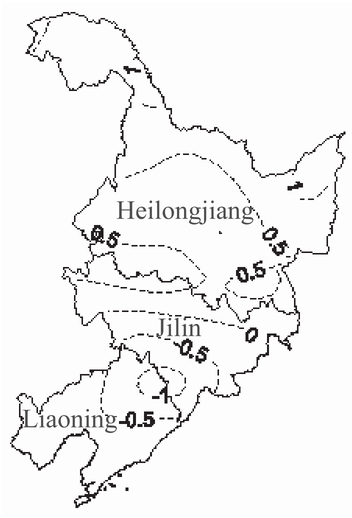


FIGURE 3

Isoline of difference of T_{5-9} standard deviations between the period of 1960-1979 and 1990-1999 in Northeast China

The Skewness-Kurtosis test indicated that the $T_{5\text{-}9}$ data obeys normal distribution during the selected cold and warm periods. Extreme climate events are defined as the probability of the event is not higher than 10 percent (Ding Yi-hui et al., 2002). Calculated from the formula (6), 80.34 degrees Celsius and 86.78 degrees Celsius are the critical accumulated temperatures ($T_{5\text{-}9}$) where the probability is less than or equal 10 percent during the cold period (1960-1979). So all the $T_{5\text{-}9}$ lower than 80.34 degrees Celsius or higher than 86.78 degrees Celsius may be regarded as extreme accumulated temperatures referring to the period from 1960-1999. During the warm period, the probability of accumulated temperature lower than 80.34 degrees Celsius was not higher than 0.23 percent, and the probability of accumulated temperature higher than 86.78 degrees Celsius was not higher than 37.5 percent (Figure 4a). The same results were found in Jilin Province and Liaoning Province (Figure 4b and Figure 4c).

In sum, the probability of extreme cold years decreased and the probability of extreme hot years increased in Northeast China during this time period.

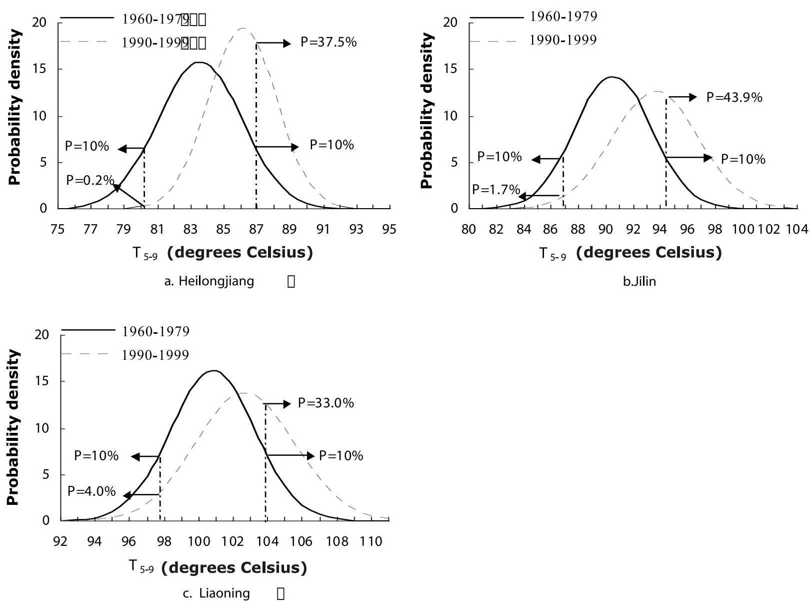


FIGURE 4

Changes of temperature probability (P) for cold and warm periods in Northeast China

The accumulated temperatures (T_{5-9}) in the North increased higher than that in South. At the same time, higher temperature variability appeared in the southern part of the region, and lower temperature variability appeared in the northern part of the region.

2.2 The impact on rice yield per-unit-area of climate warming

The expected rice yields per unit area of the main counties in Northeast China are calculated using formula (2) during the cold period and the warm period for different rice varieties of earliest ripe, early ripe, medium ripe, medium-late ripe and late ripe. It is found that during the cold period, the earliest ripening variety and early ripening variety of rice have their maximum expected yield in the north of Heilongjiang Province and the east of Jilin Province; the medium ripening variety of rice has its maximum expected yield in the middle part of Heilongjiang Province; and the medium-late ripening and late ripening varieties of rice have their maximum expected yield in Liaoning Province and the western part of Jilin Province.

As the climate warmed in the 1990's, the medium ripening variety of rice had its maximum expected yield instead of early ripening variety in some areas of northeastern Heilongjiang Province and the middle-western areas of Jilin Province. The expected yield of the late ripening variety of rice became the maximum even in some places of west-southern Heilongjiang Province and western Jilin Province (Figure 5).

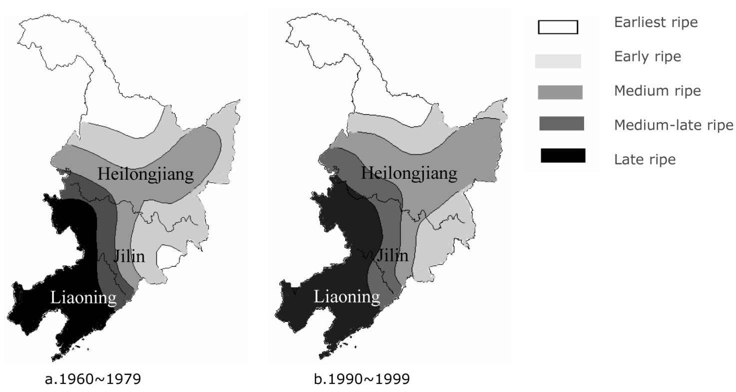
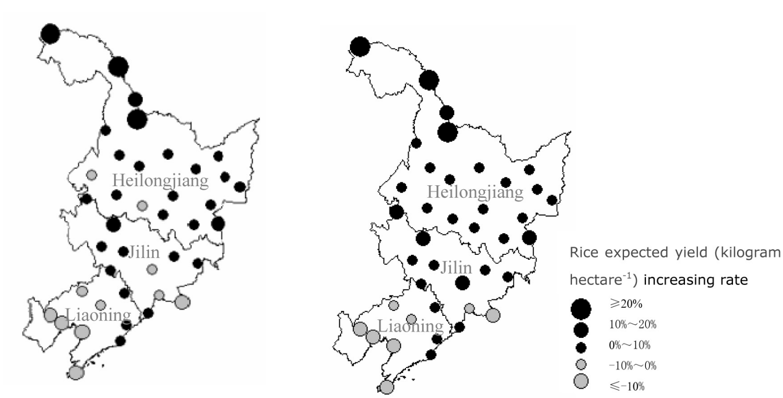


FIGURE 5

Distribution of maximal expected yield (kilogram hectare^{-1}) of different rice varieties in Northeast China

There are two main adaptation choices for changing rice varieties in Northeast China as a result of climate warming (Figure 6).

1. Planting traditional varieties of rice reduces the risk of cool summer extremes, and increases the expected yield per unit area due to the climate warming in northern Northeast China and some mountainous areas by more than 10 to 20 percent. In most areas of Heilongjiang and Jilin provinces, the expected rice yield per unit area increases about 0 to 10 percent. On the contrary, the expected rice yield per unit area in most areas of Liaoning province decreases as the climate warms.
2. In some areas of Northeast China, the originally planted variety of rice does not reach its maximum expected yield under the new temperature conditions. These could be replaced by the rice variety that provides the highest expected yield for the area. If farmers keep planting traditional varieties in some areas of Heilongjiang Province and Jilin Province, the expected yield of rice will decrease by about 0 to 10 percent due to climate warming. If farmers planted the rice varieties that need more heat, expected yields could increase by about 0 to 10 percent.



a. Not changing varieties b. Changing varieties

FIGURE 6

Compare increase rate (%) of changing varieties with no changing varieties in Northeast China

2.3 Rice sown area and yield per-unit-area in the past 20 years

2.3.1 Rice yield per-unit-area and climate warming

According to statistical data from 1978 to 1999 in Northeast China, the rice yield per unit area increased remarkably in the three provinces (Figure 7). Generally speaking, technology is the major factor that increases crop yield per unit area, but the impact of climate warming cannot be ignored. Figure 7 presents that the real rice yield per-unit-area of Jilin Province increased highest, and rice yield per-unit-area of Liaoning province increased lowest of the three provinces.

Heilongjiang Province and Jilin Province are short of the temperatures necessary to increase rice yields, so increasing the heat resources are more useful for these two provinces. According to the model, if farmers replaced rice varieties to adapt to climate warming, the expected yield per unit area would be much larger in both Heilongjiang Province and Jilin Province.

The late ripening variety of rice that is planted mainly in Liaoning Province is near its highest limit of optimum temperature for growth. So the expected

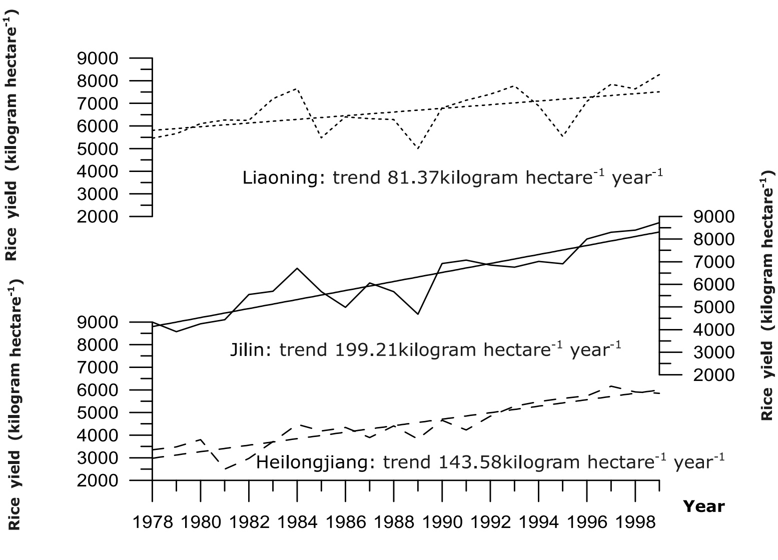


FIGURE 7

Chang of rice yield (kilogram hectare^{-1}) in the Northeast China (1978~1999) rice yield per unit area will decrease due to warming. This may be reflected in the lower increase in rice yield per unit area in Liaoning Province than the other two provinces. Climate warming has increasingly positive impacts on rice in Heilongjiang and Jilin provinces; however, these impacts are limited in Liaoning province.

2.3.2 Rice sown area and human adaptation

Human adaptation to climate warming includes not only changing the varieties of one kind of crop, but also adjusting the structure of planting. Major structural changes in planting crops can overcome adversity caused by climate change (Olesen and Bindi, 2002). The ratio of sown area is often applied to reflect the changes in the structure of planting. Rice has the largest income per unit area of grain crops. Therefore, as long as heat and irrigation satisfy rice demands, farmers will choose rice for a higher economic benefit.

Figure 8 shows that the ratio of rice sown area to main grain (rice, wheat, maize) sown area increased from 5.5 percent in 1978 to more than 30 percent in 1999 in Heilongjiang Province, and increased from 11.8 percent (1978) to 16.0 percent (1999) in Jilin Province. In Liaoning Province, the ratio of rice sown area to main grain (rice, wheat, maize) sown area increased a little in the 1980's, and declined in the 1990's.

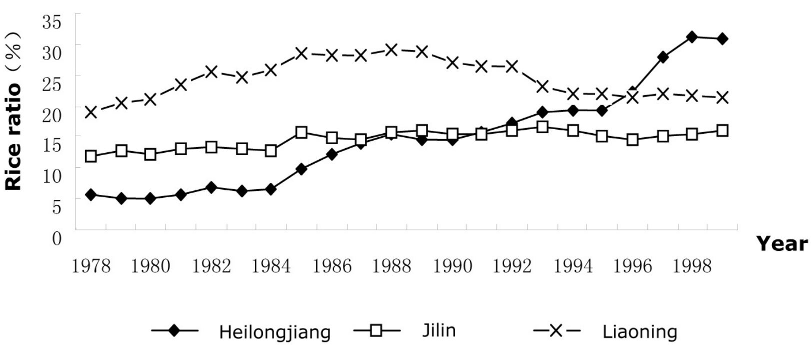


FIGURE 8

Ratio (%) of rice sown area to main grain (rice, wheat, maize) sown area in the Northeast China

In terms of the results of the model, the negative impacts of climate warming seem partly to induce the decrease in rice sown areas in Liaoning Province. The positive impacts of climate warming are likely to induce the growth of rice sown areas in Jilin Province and Heilongjiang Province. In Heilongjiang Province, rice sown areas expanded (Figure 8), where the north boundary of rice has shifted remarkably both northward and eastward.

3. Conclusion

Climate warming may produce positive or negative effects on agriculture, and this will require adaptation to new climatic conditions. In this paper, Northeast China is chosen as a case study to examine the effects and adaptations on rice crops when climate becomes warmer. A decision-making model was created to calculate the expected rice yield per unit area with accompanying heat resources. The model was used to assess the impact on rice production of changing suitable varieties under the new climate conditions. Comparing the results of model with the statistical data, it was found that increasing heat resources affected the rice yield per unit area trend in Northeast China, and that farmers can adjust their planting structure and rice varieties to adapt to climate warming. In sum, there are several conclusions.

1. Climate warming leads to an increase in the probability of extreme warm years and a decrease in the probability of extreme cold years. The increase in temperatures in the north is more remarkable than those in the south of Northeast China. Higher temperature variability appears in the southern part, and lower temperature variability appears in the northern part.
2. On the assumption that farmers ideally select the dominating rice variety that has a maximum expected yield to adapt to the climate of the period, pure impacts of climate warming will induce the rice variety that needs more heat to shift northward and eastward (if technological development is ignored). If farmers keep planting traditional rice varieties, the expected yield per unit area in Heilongjiang Province and Jilin Province will increase as warming provides more favorable temperatures for rice production. If farmers changed these rice varieties to adapt to a warmer climate, the expected yield per unit area will increase more. In a large part of Liaoning Province, the impact of climate warming to the expected yield of rice will be negative.

3. Real rice yield per unit area in Jilin Province and Heilongjiang Province increased higher than that in Liaoning Province in the past 20 years. Increasing heat resources affects the trend of rice yield per unit area. To avoid or reduce negative effects and exploit possible positive effects, farmers should expand rice sown areas in Heilongjiang Province and Jilin Province, but reduce rice sown areas in Liaoning Province. This fact demonstrates that humans can adjust planting structure to adapt to climate change.

This paper pays attention to heat resources and human adaptations. However, there are other factors that affect rice production in Northeast China. Some of these issues should be studied further such as the following.

1. A quadratic polynomial that approximates the relationship between temperature and yield per unit area is not the most precise model. More accurate data and models are needed to calculate the expected yield.
2. Other factors affect crop yield. Water resources are an important factor that affects rice yields. Although a serious drought took place after 1999 in the Northeast China (Xie an, 2003), and in the period (1960-1999) that was discussed in this paper, water was not the major limiting factor. The impact of water resources on rice production, however, could become more important in the future. In addition, human factors such as agricultural policies and technology are also important factors to be studied.
3. Human adaptation activities are also affected by other factors. In practice, farmers might select the variety for an extreme warm year or extreme cold year, instead of the average climate conditions. Price or the risk of a cool summer extreme often makes the farmer avoid the rice variety that has the maximum expected yield per unit area. Moreover, farmers often cannot take action in time. So the "adaptation lag" and the farmer's capacity to endure risk need to be studied.

4. Acknowledgements

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