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ORIGINAL PAPER

The relative contribution of climate and cultivar renewal to shaping rice yields in China since 1981

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Abstract Rice is one of China's most important staple food crops, where the yields are strongly influenced by climate and rice variety renewal. Using high-quality weather data, rice growth, and agricultural practice data, the contribution of climatic variation on rice yield increases was analyzed from 1981 to 2009 in Wuchang, Northeast China. In this region, the annual mean surface air temperature increased by 0.6 °C/decade, and the accumulated temperature (>10 °C) increased by 120.1 °C/decade from 1981 to 2009, mainly related to global warming. During the same period, rice yields increased by 2,095 kg/ha*decade. To quantify the contribution of climate change to rice yield increases, a "climate similarity index" was devised, where the most important climate parameters for rice growth were compared among years. If the rice variety was changed between 2 years, while the climate conditions were similar, any yield change would be attributed to a rice variety renewal effect. Conversely, changes in rice yields that were not associated with variety changes were attributed to climate change. Our results showed that over the analyzed period, the influence of climate on yields was estimated to 805 kg/ha per decade, while the increasing trend due to rice variety renewal was estimated to 1,290 kg/ha per decade. Thus, 38 % of the yield increases can be related to climatic variation and the remaining 62 % to changes in rice varieties. Furthermore, the effect of variety renewal on the rice yield increases was more pronounced before the 1990s, while afterward, the yield increases were mainly influenced by climatic variations in Northeast China.

1 Introduction

Rice is one of the most important cereals as a primary source of food in the world, accounting for 27.3 % (678.7 billion kg) of the total cereal production in 2009 (http://www.stats.gov.cn). In China, agriculture has undergone tremendous structural changes over the last decades. The average staple crop productivity has doubled in the last 30 years, while the population increased by 13.8 % (China Statistical Yearbook (CSY) 2011). Rice is one of China's most important staple food crops, with a total farming area of nearly 29.9 million hectares and a production exceeding 195 million tons in 2010 (China Statistical Yearbook (CSY) 2011). Rice production in China constitutes a large part of the global total production (28.4 % in 2009, FAOSTAT 2011) and thus has a significant influence on the world rice market. Over the past six decades, rice production in China has increased by more than three times due to increased grain yield per hectare and increased planting area (Peng et al. 2008).

Climate variations from daily to interannual timescales affect a number of physical, chemical, and biological processes that drive the productivity of rice. The latitudinal distribution of rice is a function of climate as well as the daily exposure of light (the photoperiod). In China, rice growth and productivity are also strongly influenced by temperature and precipitation. Averaged over the whole country, the annual mean surface air temperature (SAT) has risen by 0.03–0.12 °C/decade since 1900 (Ren et al. 2012), approximately

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0.25 °C/decade since 1951 (Ren et al. 2005, 2012), and 0.45± 0.13 °C/decade during the most recent period (the satellite era, 1979–2006) (Li et al. 2010). In the Heilongjiang province, northeastern China, the SAT has increased by 0.3–0.6 °C/decade from 1961 to 2012, which is higher than the country-averaged SAT. Despite increasing trends in droughts in North and Northeast China and intense precipitation events appeared in the Yangtze River basin and Southeast China (Zhai et al. 1999; Ren et al. 2011, 2012), no significant long-term trend in total rain-season precipitation has been observed for China as a whole for the last five to six decades, but the precipitation in the Heilongjiang province has changed negatively slightly (Song et al. 2011; Ren et al. 2012). Moreover, in the coming century, the global average SAT is projected to increase by 1.4 to 5.8 °C, as a result of increasing concentrations of atmospheric carbon dioxide and other greenhouse gases (IPCC 2007), which will have significant impacts on regional climates (Qian et al. 2005; Ding and Ren 2008; Piao et al. 2010).

According to recent studies, the effects of the ongoing climate change on crop production in China have been positive for rice and soybean and negative for wheat and maize (Tao et al. 2008; Zhang et al. 2010; Li et al. 2011). For example, Xiong et al. (2005) pointed out that maize yield would decrease in the main production regions, such as the Northeast and North China plains and the Southwest at a range of 0–25 % by the 2080s. Tao et al. (2008) made a detailed study of climate-yield relationships in China at provincial scales and discussed response mechanisms underlying their observed climate-yield relationships. They found climate warming to have positive (negative) impacts on yields depending on whether the current temperature was less (more) than the optimum temperature for the yields, indicating that small increases in temperature can have large effects on yields. Lobell et al. (2008) studied probability distributions of production changes using multimodel output (20 GCMs) and found median changes of less than 5 % for all crops (groundnut, soya bean, sugarcane, potato, maize, rice, and wheat), with only two crops showing slight decreases (maize and rice) and the others showing slight increases by 2030. However, evaluating the contribution of climatic variation on crop yields is not an easy task, since crop growth is a function of dynamic, nonlinear interactions between weather, management, and the use of new varieties (Hansen et al. 2006). Various methods have been applied to eliminate the effects of technological changes, and linear regression models have been developed to evaluate the response of crop yields to weather factors in the USA (Lobell and Asner 2003), Mexico (Lobell et al. 2005), Africa (Lobell et al. 2011), and China (Tao et al. 2008). Using a biophysical model developed for assessing carbon budget in an agroecosystem, the Agro-C model (Huang et al. 2009) and census yields, Yu et al. (2012), found that the increase in average rice yields for the whole of China over the past three decades could be attributed to changes in climate (4.4 %), management (9.3 %), and crop varieties (38.9 %) . Of course, the statistical methods can give a more reasonable contribution of different impact factors to shaping rice yields if there was enough observed information.

The increase in rice production in China is due to increased grain yield per hectare and increased planting area (Peng et al. 2008), where the increase in yields can be attributed to crop variety renewal and application of fertilizers as well as climate change. In order to adapt rice production to a future climate, it is very important to understand how much the present climate change has influenced yields. However, few studies have analytically explored how multiple factors, such as climatic variation and crop variety renewal, have contributed to changes in rice yield in China based on actual observations. In this paper, we use a simple method to separate the effects of climatic variation and technological advances (mainly changes in rice variety) on rice production trends using high-quality meteorological data, observed yields, as well as the application of fertilizers and crop variety renewal, in Wuchang, the Heilongjiang province in Northeast China. More specifically, the estimated contribution of climatic variation to rice yield trends will be more realistic, since the climate and yield data were observed from the same station.

2 Material and methods

2.1 Study region

The Wuchang observational station (127.2°E, 44.9°N), located in the Heilongjiang province, Northeast China, has an annual mean SAT of 4.3 °C from 1971 to 2000, with the summer being rainy and warm (monthly mean SAT ranging from 18 to 25 °C) and the winter being very dry and cold (monthly mean SAT ranging from −20 to −10 °C). The total annual precipitation generally ranges from 400 to 1,000 mm. The area of the Wuchang observational station encompasses 0.52 ha, and the field can be irrigated from a river nearby. The soil is black soil with contents of organic material reaching 5.64 %, 0.257 % nitrogen, 0.006 g/kg phosphorus, and 0.226 g/kg potassium (China Soil Survey Office CSUO 1995), indicating that the soil is very fertile. Rice is usually planted in May when the SAT reaches 10–15 °C and harvested in September. It is understandable that the rice is more sensitive to temperature than precipitation because the rice field can be irrigated.

2.2 Data

In order to investigate the contribution of climatic variations to the increasing rice production in Northeast China, daily mean SAT, precipitation, and sunshine hours, provided by the China Meteorological Administration (CMA) for the period 1958–2009, were used (Wuchang station was built in 1958).

Rice growth and yields have been monitored every 10 days since 1981 by the CMA. The rice growth information includes rice variety, fertilization amount, planting date, tilling date, flowering date, maturity date, and the tallness and density of the plants. The dataset also includes the information on the dates of meteorological disasters, plant diseases as well as insect pests, and their observed influences on rice (Table 1).

Table 1 Observation items in the Wuchang observational station

Observation items
Rice growth
1. Planted date
2. Tillering date
3. Flowering date
4. Maturity date
5. The height of plant
Soil moisture
6. Soil moisture in 10 cm of soil
7. Soil moisture in 20 cm of soil
8. Soil moisture in 30 cm of soil
9. Soil moisture in 50 cm of soil
Disasters
10. The date and effect of meteorological disasters
11. The date and effect of diseases and insect pests
Meteorological data
12. Daily mean temperature
13. Daily maximum temperature
14. Daily minimum temperature
15. Daily precipitation
16. Daily sunshine hours
Yield
17. Yield

2.3 Methods

(1) Defining climate similarity index

Generally, rice yields are mainly influenced by climate and technological changes. Regarding climate, temperature, precipitation, and sunshine hours have effects on rice growth. Consequently, the correlation coefficients between rice yields and temperature, precipitation, and sunshine hours during the growing season (from May to September) were calculated. It was noted that rice yields were significantly correlated with the accumulated temperature (r=0.57 with significance at 0.01 level), showing the importance of accumulated temperature for rice yields. The correlation coefficient between rice yields and precipitation was only −0.2, indicating that the rice yields are not significantly influenced by precipitation. This is mainly due to the rice fields being irrigated from a nearby river. The correlation coefficient between rice yields and sunshine hours was −0.41, also suggesting a limited influence on rice growth. Furthermore, during 1971–2000, the average sunshine hours during the growing season in Northeast China were 1,181 h, while rice growth in the region needs 1,000 sunshine hours (Cheng and Li 2007), indicating no shortage of sunshine. Thus, we may conclude that the rice yields were mainly influenced by temperature and technological changes.

In our approach to separate climatic variation from technological changes, we first devised an index based on the weather variables most strongly associated with rice yields. This would enable us with a simple mean to study the effects on rice yields of management etc., in years with similar weather. Thus, using the found relation between rice yields and temperature, a "climate similarity index" (Wei 2007) for the growing season was created, formulated as follows:

$$CS = 1 - \frac{1}{n}\sum_{i=1}^{i=n}\frac{x_{ai}-x_{bi}}{x_{bi}} \tag{1}$$

CS The climate similarity index

X_{ai} The daily mean temperature in day i during May to September of year a

X_{bi} The daily mean temperature in day i during May to September of year b

If the CS calculated for 2 years was ≥0.98 (Fig. 1), the climate in those years was considered to be similar.

(2) The method of separating the contribution of climatic variations to increased yields.

The yields of rice doubled in the last 30 years in Northeast China (China Statistical Yearbook (CSY) 2011), mainly induced by technological changes (e.g., rice variety change and fertilization application) and climatic change. In the Wuchang observational station, fertilization was decreased because of the fertility of the soils (Table 2), and the increase in rice yield was mainly induced by rice variety renewal and climate. Consequently, if the original rice variety was changed to a new one between 2 years with similar climate conditions, the yield change would be induced by rice variety renewal. This can be expressed as follows:

$$\mathrm{Y}_{\mathrm{vc}} = \mathrm{Y}_{\mathrm{new}} - \mathrm{Y}_{\mathrm{old}} \tag{2}$$

Y_{vc} The yield change induced by rice variety renewal

Y_{new} The yield of a new rice variety under similar climate conditions

Y_{old} The yield of the original rice variety under similar climate conditions

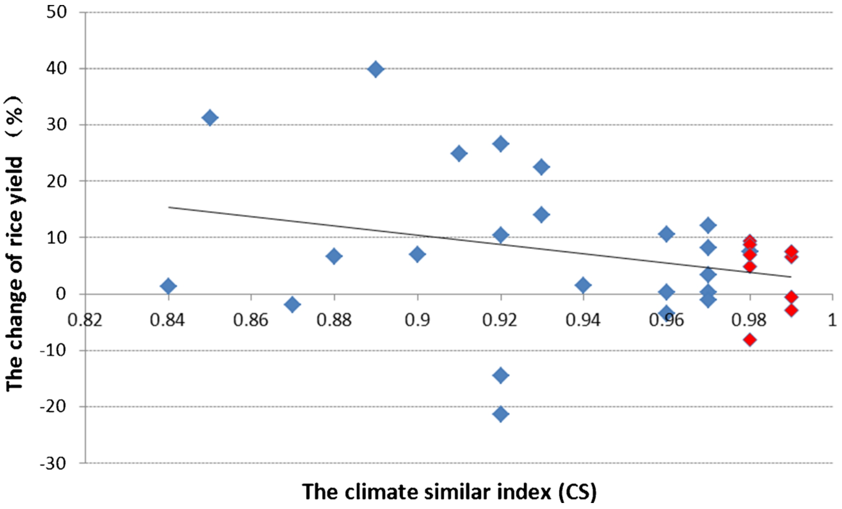


Fig. 1 The change of rice yields along with the climate similarity index (CS) for the same rice variety in the Wuchang station of China (The *red squares* indicate that rice yields changed slightly when CS was higher than 0.98)

Table 2 The information about rice planting in the Wuchang observational station

Year	Varieties of rice	Nitrogen fertilizer (kg/ha)	Disasters
1981	XX14-1	70.0	
1982	XX14-1	70.0	Drought
1983	XX14-1	70.0	
1984	XX14-1	70.0	
1985	XX14-1	70.0	More rain days
1986	XB-2	175.0	
1987	ZM-3	175.0	
1988	C19-4	93.3	
1989	C19-4	70.0	Drought
1990	C19-4	69.0	
1991	985-5	69.0	
1992	DL5-6	69.0	Low temperature
1993	DL5-6	69.0	
1994	DL5-6	69.0	
1995	DL5-6	69.0	
1996	DL5-6	69.0	
1997	C19	55.2	
1998	T35-7	69.0	
1999	T35-7	55.2	
2000	T35-7	69.0	
2001	938-8	69.0	
2002	938-8	55.2	
2003	938-8	55.2	Drought
2004	938-8	55.2	
2005	938-8	55.2	
2006	938-8	55.2	
2007	DXC-9	55.2	
2008	DXC-9	55.2	
2009	DXC-9	55.2	

From the above formula, we can get an estimation of the contribution of variety renewal to increasing rice yields. For example, a rice variety called “XX14-1” was planted at the Wuchang station during 1981–1985, and a new variety called “XB-2” was planted in 1986, so the climatic similar indexes were calculated between 1986 and the individual years from 1981 to 1985. The index reaches 0.99 when the years 1986 and 1984 are compared, indicating that the weather during the rice growing season in the 2 years was highly similar. This means that the observed yield change, or an increase by 450 kg/ha, in 1986 compared with 1984, was mainly induced by the introduction of the new rice variety. Using this method, the contribution of variety renewal to increasing rice yields was calculated. Consequently, if the yield change induced by rice variety renewal is removed from the observed yield, then the residual yield would mainly be linked to climate, and thus, the contribution of climatic variation to the production could be estimated.

3 Results

3.1 Climate evolution in Wuchang

The annual mean SAT in Fig. 2 shows large interannual variability and an increasing trend with 0.5 °C/decade from 1961 to 2009 (0.6 °C/decade from 1981 to 2009) at the Wuchang station, which is close to the observed change for Northeast China but higher than that for mainland China (0.3 °C/decade) (National Climate Center, China Meteorological Administration 2010). The decadal mean SAT increased from 3.4 °C in the 1960s to 4.0 °C in the 1980s,5.0 °C in the 1990s, and 5.2 °C during 2000–2009. These results clearly show an apparent increase from the 1980s. At the same time, the accumulated temperature (>10 °C) also show increasing trends by 84.9 °C/decade during

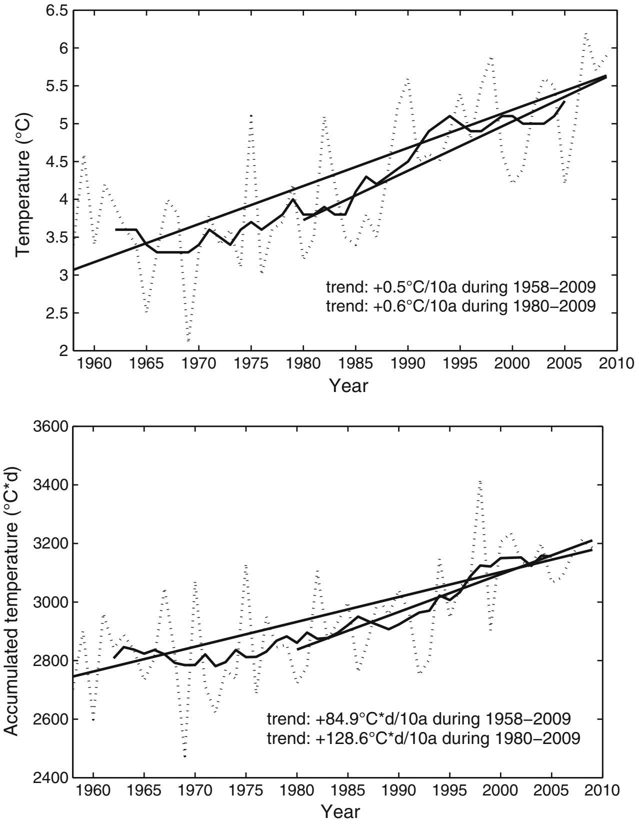


Fig. 2 Time series of the annual temperature (*up*) and the average accumulated temperature (>10 °C) (*down*) at the Wuchang station in China from 1958 to 2009

1961–2009 and 120.1 °C/decade during 1981–2009. For example, the average accumulated temperature was only 2,847 °C in the 1960s but has increased continuously (2,901 °C in the 1980s and 3010 °C in the 1990s) amounting to 3,160 °C in 2000 to2009. Thus, from 1961 to 2009, the annual mean SAT has increased by 0.5 °C/decade and the accumulated temperature by 84.9 °C/decade.

The thermal conditions are the main limiting factor for rice, since rice often cannot fully mature after the first frost in Northeast China. Generally, yields of rice increase when the accumulated temperature (>10 °C) amounts to 3,500 °C in a year (Cheng and Li 2007). As an example, the average accumulated temperatures during 2001–2009 only amounted to 3,157°C in the study area, and as a result, the thermal conditions were not sufficient for rice growth. For example, the corn and rice had not matured fully due to less accumulated temperature in Northeast China in 1969, and the production was decreased by 20 % (Guo and Ma 2009). So the increasing temperature and accumulated temperature were positive factors for crop growth in Northeast China where thermal condition was usually deficient due to the high latitude.

At the Wuchang station, the annual total precipitation amounted to about 600 mm, with about 500 mm falling during the growing season (May to September). Annual precipitation decreased slightly by 18.7 mm/decade during 1961–2009, but for the recent time period 1981–2009, it decreased by 36.4 mm/decade. Annual precipitation was on average 657 mm in the 1960s and 569.0 mm in the 1990s, resulting in a decrease of 88 mm (Fig. 3). Although the precipitation was decreasing slightly, rice growth was not influenced since it was irrigated from a nearby river, where the water of the river is affected by the precipitation over its upper reaches. In extreme drought years, however, the rice yields may be influenced by a shortage of water from the river affecting the irrigation. According to observations, there was no water available for irrigation from this river in the years 1982, 1989, and 2003. As a result, there was a significant negative influence on the rice yields in those years.

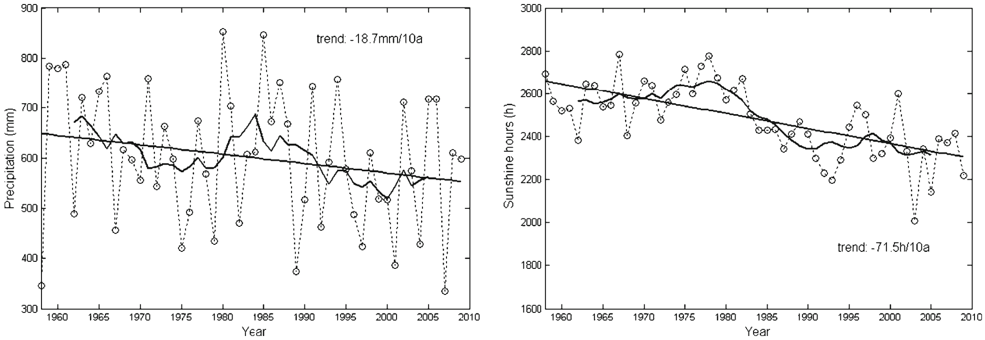
Sunshine hours also changed during 1958–2009, where the annual amount of sunshine duration decreased by 71.5 h/decade in the Wuchang station (Fig. 3), which was in line to that of China as a whole (Song et al. 2005; Ding and Ren 2008). In the 1960s and 1970s, the average sunshine hours during the growing season (May to September) were 1,198 and 1,255 h, respectively, while the average sunshine hours have continuously decreased to 1,181, 1,116, and 1,101 h for the 1980s, 1990s, and 2000–2009, respectively. Because rice growth needs at least 1,000 sunshine hours during the growing season (Cheng and Li 2007), the significant decrease in the last few decades likely did not have a negative impact on rice growth. However, if the trend continues, it may become a problem in the future.

3.2 The changes of rice yields and varieties

The observed rice yields at the Wuchang station from 1981 to 2009 showed a steady long-term increase (Fig. 4). The mean yield of rice was 4,838 kg/ha from 1981 to 1989, increased to 7,484 kg/ha in the 1990s, and amounted to 8,681 kg/ha during 2000–2009. This means an increase of 79 % from the 1980s to the 2000s. The lowest yield, 3,502 kg/ha, was recorded in 1982, and the highest yield was obtained in 2008, amounting to 10,400 kg/ha. Overall, the rice yield increased by 2,095 kg/ha per decade at the Wuchang station during 1981–2009.

It is clear that the observed increasing trend in rice yields has mainly been influenced by technological progress. For China, a large developing country, a rapid scientific progress in agriculture is evident; rice varieties at Wuchang were changed ten times from 1981 to 2009, i.e., one new rice variety was being introduced every 3 years on average (Table 2). Furthermore, a nitrogen fertilizer at Wuchang was used mainly from 1981 to 2009. Table 2 shows that the use of fertilizer was decreasing at the Wuchang station, and due to the high fertility of the soils, we assumed that fertilization only had a minor impact on the increasing rice yields, especially during 1990–2009. Consequently, we presumed that the

Fig. 3 Time series of the annual precipitation (*left*) and annual sunshine hours (*right*) at the Wuchang station in China from 1958 to 2009



increased yields were induced mainly by rice variety changes and climatic variation.

3.3 The contribution of climatic variations to rice yield increases

When the climatic similar indices were calculated, the years with recorded drought were excluded (1982, 1989, and 2003) due to the reasons given above.

Years with similar climates are shown in Table 3. The climatic similar indexes showed, for example, that the growing season climate was highly similar in 1986 and 1984 (0.99). It may be deduced that the yield change was induced by variety renewal. The rice yield of 4,650 kg/ha in 1984 was obtained with the rice variety “XX14-1”, while the yield of 5,100 kg/ha in 1986 was obtained with the rice variety “XB-2”. The rice yield change induced by rice variety renewal was thus removed from the observed rice yields (Table 3).

Figure 4 shows that rice yields due to climatic variation increased by 804.8 kg/ha per decade, while the yields due to rice variety renewal increased by 1,290.2 kg/ha per decade. Therefore, the overall increase of rice yields at the Wuchang station was 2,095 kg/ha per decade, of which, 38.4 % can be attributed to climatic variation and 61.6 % to the changes in rice variety. Furthermore, in the period 1981–1994, rice yields were strongly influenced by rice variety renewal, with average increases of 537 kg/ha for every variety renewal. The yields induced by climatic variation showed a slight change from 1981 to 1995, with the mean yields being 4,444.5, 4,567.5, and 4,532.5 kg/ha for every 5 years during 1981–1995. Therefore, the yields generally increased during 1996–2003, but a more prominent increase occurred after 2004, with yields increasing from 6,000 in 2004 to 7,219 ka/ha in 2009. The results indicate that the influence of climatic variation on rice yields has been clearly positive in the study area, and the significant increase in SAT since the beginning of the 1990s might have played a key role.

4 Discussion and conclusions

Rice is one of the most important staple crops in China, where rice yields are strongly influenced by climate and rice variety renewal. Using the high-quality weather data, rice growth, and agriculture practices data, the contribution of climatic variation to rice yield increase was analyzed from 1981 to 2009.

The results showed that the annual mean SAT was increased by 0.6 °C/decade from 1981 to 2009 in the Wuchang observational station, and the accumulated temperature (>10 °C) showed an increasing trend of 120.1 °C/decade due to the climatic variation. During the same time period, the rice yields were observed to have increased by 2,095 kg/ha per decade at the Wuchang station, where 10 rice variety renewals were recorded.

Using the climate similarity method, the contribution of climatic variation to rice yield increase was calculated.

Fig. 4 The change of observed rice yields (*left*) and the contribution of climate change and rice variety renewal to increasing rice yield (*right*) from 1981 to 2009 at the Wuchang station in China

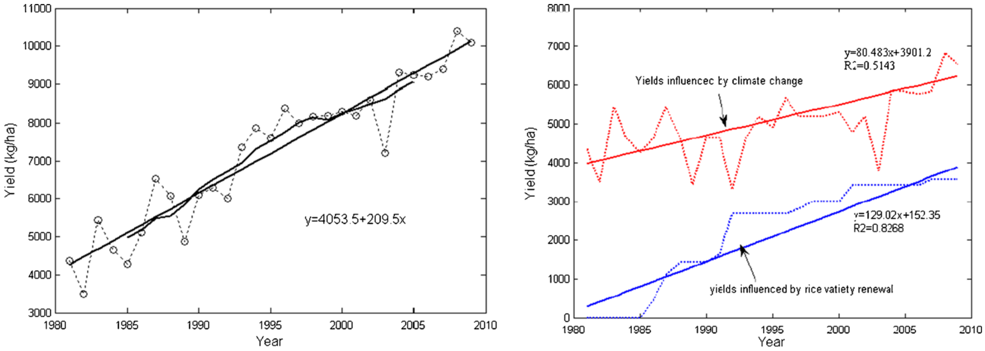


Table 3 The information about yields, varieties of rice, and climate similarity indexes in Wuchang from 1981 to2009

Year	Yields(kg/ha)	Varieties of rice	Climate similarity indexes (CS)	Increased yields by varieties (contrasting XX14-1)	Yields influenced by climate change
1981	4,357.5	XX14-1		0	4,357.5
1982	3,502.5	XX14-1		0	3,502.5
1983	5,437.5	XX14-1		0	5,437.5
1984	4,650.0	XX14-1		0	4,650.0
1985	4,275.0	XX14-1		0	4,275.0
1986	5,100.0	XB-2	0.99 (between 1986 and 1984)	450.0	4,650.0
1987	6,525.0	ZM-3	0.98 (between 1987 and 1983)	1,087.5	5,437.5
1988	6,075.00	C19-4	0.98 (between 1988 and 1984)	1,425.0	4,650.0
1989	4,860.0	C19-4		1,425.0	3,435.0
1990	6,090.00	C19-4		1,425.0	4,665.0
1991	6,300.0	985-5	0.97 (between 1991 and 1984)	1,650.0	4,650.0
1992	6,000.0	DL5-6		2,685.0	3,315.0
1993	7,350.0	DL5-6	0.99(between 1993 and 1990)	2,685.0	4,665.0
1994	7,868.7	DL5-6		2,685.0	5,183.7
1995	7,593.8	DL5-6		2,685.0	4,908.8
1996	8,387.0	DL5-6		2,685.0	5,702.0
1997	7,992.20	C19	0.99(between 1997 and 1994)	2,808.5	5,183.7
1998	8,176.7	T35-7		2,993.0	5,183.7
1999	8,195.1	T35-7	0.98(between 1999 and 1997)	2,993.0	5,202.1
2000	8,300.0	T35-7		2,993.0	5,307.0
2001	8,200.0	938-8		3,416.3	4,783.7
2002	8,600.0	938-8	0.99(between 2002 and 1998)	3,416.3	5,183.7
2003	7,200.0	938-8		3,416.3	3,783.7
2004	9,300.0	938-8		3,416.3	5,883.7
2005	9,250.0	938-8		3,416.3	5,833.7
2006	9,200.0	938-8		3,416.3	5,783.7
2007	9,400.0	DXC-9		3,566.3	5,833.7
2008	10,400.0	DXC-9	0.99(between 2008 and 2004)	3,566.3	6,833.7
2009	10,100.0	DXC-9		3,566.3	6,533.7

Evaluating the contribution of climatic variation on crop yields is not an easy task in China because the crop growth is a function of dynamic, nonlinear interactions between weather, management, and the use of new varieties. But the similar climate index method can make us understand how agriculture has responded to historic climate change in Northeast China. The observed rice yields were separated into those influenced mainly by climatic variation and those attributed to rice variety renewal. The yields influenced by climatic variation showed an increasing trend of 804.8 kg/ha per decade, which was significantly less than the trend of the yields attributed to rice variety renewal (1,290.2 kg/ha per decade). This means that 38.4 % of the increasing trend of rice yields in the study area might have been related to climatic variation and 61.6 % to the rice variety renewal. Furthermore, the strongest positive effect of introducing new rice varieties was observed prior to the 1990s, while afterwards, the effect of increasing temperatures during the growing season seemingly had a more dominating effect on rice yield increases.

This result indicated that, since the 1990s, the thermal conditions have improved to benefit the crop growth over Northeast China. At the Wuchang station, the annual mean SAT is quite low, averaging 4.3 °C, and the accumulated temperature (>10 °C) change from 2,400 to 3,500 °C*d from 1981 to 2009. The significant improvement of the thermal growing conditions during the time period hence has benefitted rice growth in the region. Berner et al. (2004) also pointed that climatic variation may advance the potential crop production at high latitudes and promote the potential number of harvests and hence seasonal yields for perennial forage crops.

Our results are in line with previous findings of the effects of climatic change on agriculture in China. Using the Agro-C model and census yields, Yu et al. (2012)) found that the increase in rice yield over the past three decades was attributed to climate (4.4 %), management (9.3 %), and variety (38.9 %) in the whole of China. Peng et al. (2000, 2008) also pointed out that genetic improvement is an important contributor to the impressive increase in rice grain yield. Some studies (e.g., Sun and Huang 2012; Xin et al. 2012) confirmed that the nitrogen fertilizer application rate per unit of harvest area decreased gradually after 1990. The same trend is also shown in Table 2, while the grain yields continue to increase. The departure of a temporal trend of the grain yield against N fertilizer application implies that N fertilizer application was not the main factor influencing the rice yield in the study area.

Our results showed that the influence of climatic variation on rice yields has so far been positive. However, if the warming continues, it is likely that accompanying increases in accumulated temperatures may eventually become harmful to the rice. Moreover, decreased precipitation may cause water shortages, e.g., with less water available for irrigation of the rice fields. Those will threaten the yields of rice in Northeast China. In fact, the rice growth depended strongly on irrigation water from rivers in most regions of northern China, while the decreasing precipitation has a strong impact on the water resources. About 40 % of the total 10,000 km of rivers had been changed from having runoff throughout the year to seasonal runoff in northern China during 1951–2000. During the same time period, the averagely annual outflow to the Pacific Ocean decreased by 80 % compared with that of the 1950s (Jia et al. 2002). These studies showed that the water resources have been influenced negatively due to the decreasing precipitation in northern China, and the irrigation for rice was influenced in severe drought years. If the water resources in the Northeast will continue to decline due to climatic variation, then the rice planting will probably be influenced more negatively in the future.

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