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Responses of rice yields to recent climate change in China: An empirical assessment based on long-term observations at different spatial scales (1981–2005)

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ABSTRACT

This empirical study (i) assessed rice yield responses to recent climate change at experiment stations, in counties and in provinces of China for the period of 1981–2005 and (ii) identified the climatic drivers determining the trend of yields at each spatial scale. Our empirical results, based on 20 experiment stations during study periods of 14–25 years, indicate that rice yields were positively correlated to solar radiation, which primarily drives yield variation. At most stations, yields were positively correlated to temperature and there was no significant negative correlation between them. Therefore, our empirical results argue against the often-cited hypothesis of lower yields with higher temperature. We explain this by the positive correlation between temperature and radiation at our stations. Empirical analysis to yield at a regional scale (20 counties and 22 provinces) indicates a varying climate to yield relationships. In some places, yields were positively regressed with temperature when they were also positively regressed with radiation, showing the similar pattern at above experiment stations. But, in others, lower yield with higher temperature was accompanied by positive correlation between yield and rainfall, which was not happened at stations. We explain this by irrigation water availability, which played a crucial role in determining climatic effects (radiation or rainfall) on yield variability at a regional scale in China. However, temperature's negative effect is still weak at any scale.

This study showed how rice yields respond to recent climate change from 1981 to 2005 at station and regional scales in China and identifies the major climatic driver for yield variation. The empirical findings presented here provide a foundation for anticipating climate change impacts on rice production in China.

1. Introduction

There is a broad agreement that global food production is and will be affected by climate change in a significant manner (Parry et al., 2004; Schmidhuber and Tubiello, 2007). Often, the term "response" is used to describe the sensitivity of yield to a change in a given climatic parameter, such as temperature, in an attempt to quantify climatic effects on crop yields (Landau et al., 1998; Lobell and Asner, 2003; Peng et al., 2004; Sheehy et al., 2006a). The response can be derived from a specific yield change with respective change in climatic parameter, for instance, in tons per hectare per degree centigrade.

An often-cited value of rice yield response to climate change was measured by Peng et al. (2004), who found rice yield correlation was more significant with minimum temperature than with other climatic parameters based on records from continuous field experiments during 1992–2003 at the International Rice Research Institute (IRRI). Rice yields declined by 10% for a one degree centigrade increase in minimum temperature. In addition, other investigators have also empirically investigated climatic effects on rice alongside of other cereals (Lobell et al., 2005; Lobell and Ortiz-Monasterio, 2007; Sheehy et al., 2006b) using regional crop yield data on a subnational scale (Lobell et al., 2007; Tao et al., 2008), national scale (Lobell, 2007), and global scale (Lobell et al., 2008). In spite of these efforts, above studies did not reach a consensus and led to new arguments. For example, Lobell (2007) found that rising of maximum temperature is more harmful to rice yields than minimum temperature in most countries, which contradicts the major negative effect of minimum temperature inferred by Peng et al. (2004). More interesting, Sheehy et al. (2006b) reinvestigated

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Table 1
Data sources and use in the study.

Scale	Data	Source	Use
Experiment station	Yield	CMA archives (2009)	To calculate rice yield response to climate change at experiment stations (Fig. 1)
	Phenology	CMA archives (2009)	To determine the time windows for calculating climate variables at stations
	Climate	CMDSSS (2009)	To annually calculate average climate variables based on phenology
County	Yield statistics	CMA archives (2009)	To calculate rice yield response to climate change at county scale
Province	Yield statistics	IRRI database (2009)	To calculate rice yield response to climate change at province scale
	Crop calendar	Maclean et al. (2002)	To determine the time windows for calculating climate variables at province scale
	Climate	CMDSSS (2009)	To annually calculate average climate variables based on crop calendar for each province (Fig. 2)
	Irrigation water quota	DSIES (2009)	To quantify irrigation water availability in each province

the IRRI dataset Peng et al. (2004) used and argued against Peng's interpretation of the yield decline and pointed toward covariation of rising minimum temperature and reduced solar radiation; thus, a decrease in solar radiation could also explain the reduction in yield. These arguments may indicate that current understanding of the impacts of temperature on crop yields is still inadequate.

The effects of climate change on rice production are particularly of concern in China since it provides staple food for Chinese people. The responses of Chinese rice yields to climate were routinely assessed by modeling studies (e.g., Matthews et al., 1995; Erda et al., 2005; Xiong et al., 2007; Yao et al., 2007), which usually show that increase in temperature have a significantly negative effect on rice yields. However, empirical study that can be used to test validity of the modeling project is still few in China and was not addressed in a systematic manner in the early works (Tao et al., 2006, 2008) since the large territory of China and diversity of growing conditions. This lack of empirical testing is a restriction for mechanistic models of rice yield responses to climate change in China.

Therefore, in this study, we showed the results of how rice yields responded to recent interannual change in climate based on variety of spatial scales in China. Extensive rice yield and climatic data were collected at the scales of experiment stations, counties and provinces. The data cover most rice production area and are of representative Chinese rice production system at different levels. The objectives were:

(i) To assess the responses of rice yields to climatic parameters at different spatial scales;
(ii) To identify the major climatic drivers for yield variations.

2. Materials and methods

2.1. Data at experiment stations, in counties, and in provinces

Table 1 summarizes the source and use for the data in the study. Crops at experiment stations were grown under optimum growing conditions, whereas crop yields in counties and provinces were obtained in the environment of local farmers' fields.

Data of experiment stations were obtained from 20 agricultural experiment stations operated by the Chinese Meteorological Administration (CMA archives, 2009), with continuous monitoring of rice phenology and yields. Optimum growing conditions were generally maintained for crop development at these experiments. The stations cover the main rice production area in China, with observation periods of 14–25 years (Fig. 1 and Table 2). Eleven stations grow one-harvest rice whereas the other nine are double-harvest rice stations. The crop data include rice phenological dates (transplanting and maturity) and field yields. Minimum temperature (T_{min}), maximum temperature (T_{max}), mean temperature (T_{mean}), sunshine hour, and rainfall (Rain) for the study period and stations were downloaded from the China Meteorological Data Sharing Service System (CMDSSS, 2009). Sunshine hour values were converted to radiation (Rad) values using the Ångström formula (Ångström, 1924).

Yield statistics in the respective counties where the above experiment stations are located (Fig. 1) were also obtained from the CMA (CMA archives, 2009) in the same study period. The original source of these county-level yields is the local county bureau of statistics, which made investigation on rice production and rice sown area for each village and aggregated to county-average yield for each season. County-level yields are not the same with those at experiment stations since the yields were produced by farmers and represent the yields on farmer's fields in counties.

Yield statistics in the 22 Chinese provinces highlighted in Fig. 2 were downloaded from the IRRI database (IRRI database, 2009), sources of which are the China Agricultural Yearbook published by National Bureau of Statistics of China. Being consistent with county level, provincial-level yields also represent yields obtained by farmers. The study period is from 1981 to 2005. For northeast, north, and northwest China (NEC, NC, and NWC), in the subhumid and semiarid region, one-harvest rice is mainly grown from April to September. The farmers in southern China (SC), the humid region, plant two-harvest rice. The main crop calendar is from February to June for the early rice season and from June to November for the

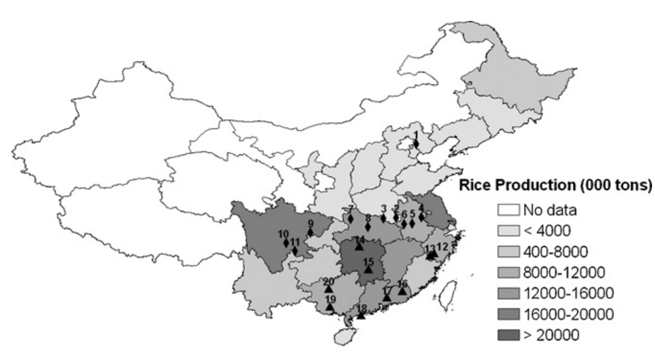

Fig. 1. The locations of agricultural experiment stations and distribution of rice production in China. ♦ indicates single-harvest rice; ▲ indicates double-harvest rice. See Table 2 for details. Rice production is the average value during 1981–2005 in the provinces (IRRI database, 2009).