WORKSHOP 02

Risk of High Temperatures on Rice Production in China: Observation, Simulation and Prediction

Fulu Tao, and Wenjiao Shi*

Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing, China

Abstract

Extreme temperature impacts on field crop are of key concern and increasingly assessed, however the studies have seldom taken into account the automatic adaptations such as shifts in planting dates, phenological dynamics and cultivars. In this present study, trial data on rice phenology, agro-meteorological hazards and yields during 1981–2009 at 120 national agro-meteorological experiment stations were used. The detailed data provide us a unique opportunity to quantify extreme temperature impacts on rice yield more precisely and in a setting with automatic adaptations.

In this study, changes in an accumulated thermal index (growing degree day, GDD), a high temperature stress index (> 35°C high temperature degree day, HDD), and a cold stress index (< 20°C cold degree day, CDD), were firstly investigated. Then, their impacts on rice yield were further quantified by a multivariable analysis. The results showed that in the past three decades, for early rice, late rice and single rice in western part, and single rice in other parts of the middle and lower reaches of Yangtze River, respectively, rice yield increased by 5.83%, 1.71%,8.73% and 3.49% due to increase in GDD (Fig. 1).

Rice yield was generally more sensitive to high temperature stress than to cold temperature stress. It decreased by 0.14%, 0.32%, 0.34% and 0.14% due to increase in HDD, by contrast increased by 1.61%, 0.26%, 0.16% and 0.01% due to decrease in CDD, respectively (Fig. 2). In addition, decreases in solar radiation reduced rice yield by 0.96%, 0.13%, 9.34% and 6.02% (Fig. 3). In the past three decades, the positive impacts of increase in GDD and the negative impacts of decrease in solar radiation played dominant roles in determining overall climate impacts on yield. However, with climate warming in future, the positive impacts of increase in GDD and decrease in CDD will be offset by increase in HDD, resulting in overall negative climate impacts on yield. Our findings highlight the risk of heat stress on rice yield and the importance of developing integrated adaptation strategies to cope with heat stress.

* Correspondence to : shiwj@igsnrr.ac.cn

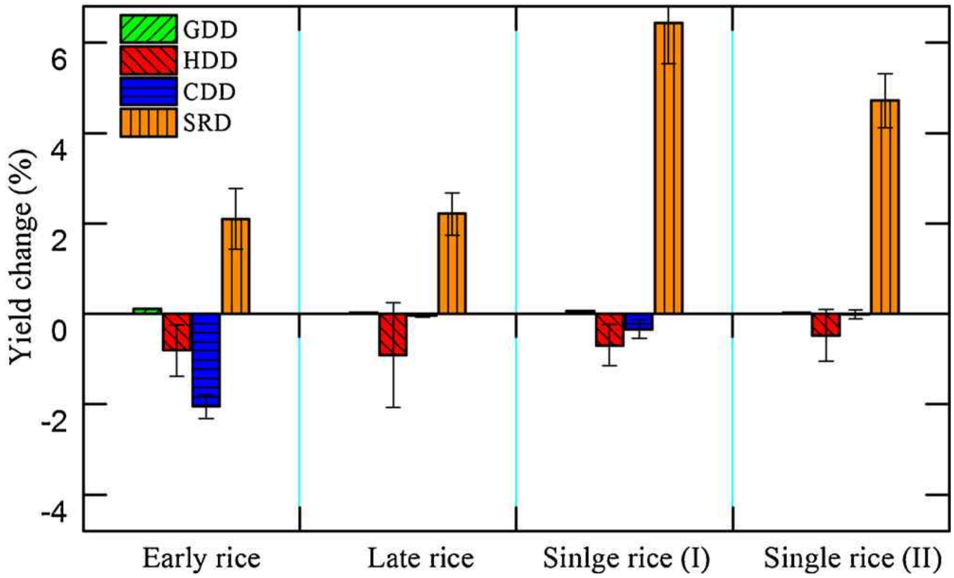

Fig. 1. Sensitivity of rice yield to GDD, HDD, CDD and SRD for early rice, late rice, single rice (I) and single rice (II), respectively.

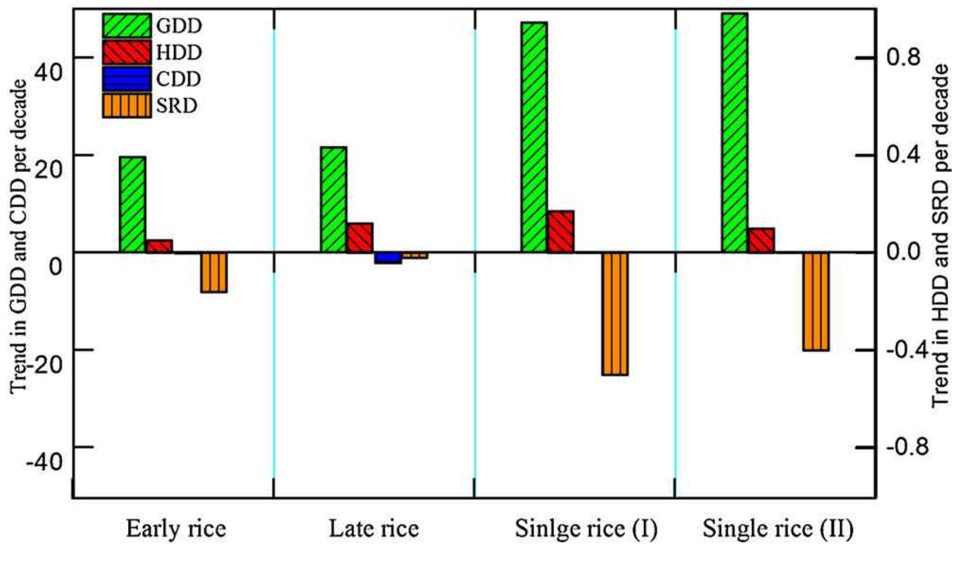

Fig. 2. Trends in GDD (degree-days/decade), HDD (degree-days/decade), CDD (degree-days/decade) and SRD ($MJ/m^2/day/decade$) during 1981−2009 for early rice, late rice, single rice (I) and single rice (II), respectively.

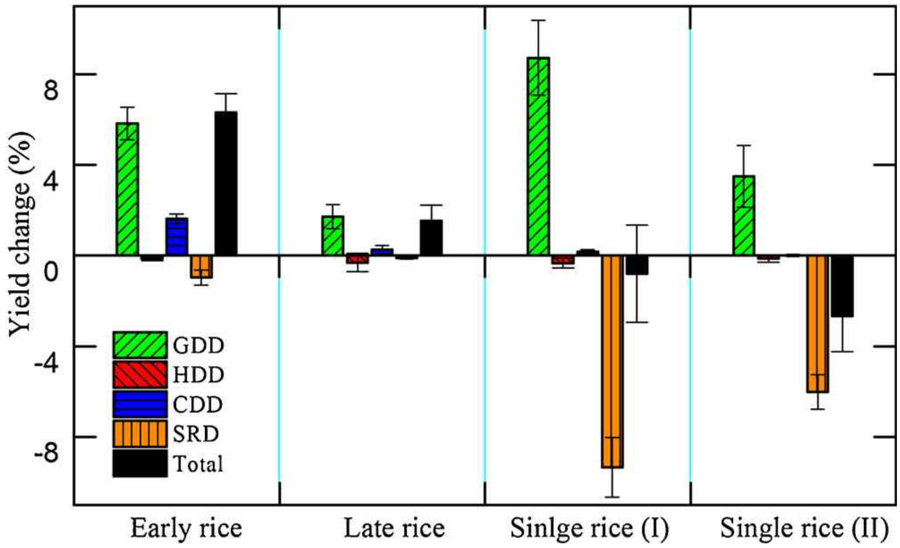

Fig. 3. Impacts of changes in GDD, HDD, CDD and SRD on rice yields during1981–2009 for early rice, late rice, single rice (I) and single rice (II), respectively.

Extreme temperature stress (ETS) is recognized as an important threat to the food supply in China. However, how much yield loss caused by ETS (YL_{ETS}) to the irrigated rice production still remains unclear. In this study, we provided a prototype for YL_{ETS} assessments by using a process-based crop model (MCWLA-Rice) with the ETS impacts explicitly parameterized, to help understand the spatio-temporal patterns of YL_{ETS} and the mechanism underlying the ETS impacts at a 0.5°×0.5° grid scale in the major irrigated rice planting areas across China during 1981–2010. On the basis of the optimal 30 sets of parameters, the ensemble simulations indicated the following: Regions I (northeastern China) and III2 (the mid-lower reaches of the Yangtze River) were considered to be the most vulnerable areas to ETS, with the medium YL_{ETS} of 18.4 and 12.9 %, respectively.

Furthermore, large YL_{ETS} values (>10 %) were found in some portions of Region II (the Yunnan-Guizhou Plateau), western Region III1 (the Sichuan Basin), the middle of Region IV_ER (southern China cultivated by early rice), and the west and southeast of Region IV_LR (southern China cultivated by late rice).

Over the past several decades, a significant decrease in YL_{ETS} was detected in most of Region I and in northern Region IV_LR (with the medians of −0.53 and −0.28 % year−1, respectively). However, a significant increase was found in most of Region III (including III1 and III2) and in Region IV_ER, particularly in the last decade (2001–2010) (Fig. 4). Overall, reduced cold stress has improved the conditions for irrigated rice production across large parts of China. Nevertheless, to improve the accuracy of YL_{ETS} estimations, more accurate yield loss functions and multimodel ensembles should be developed.

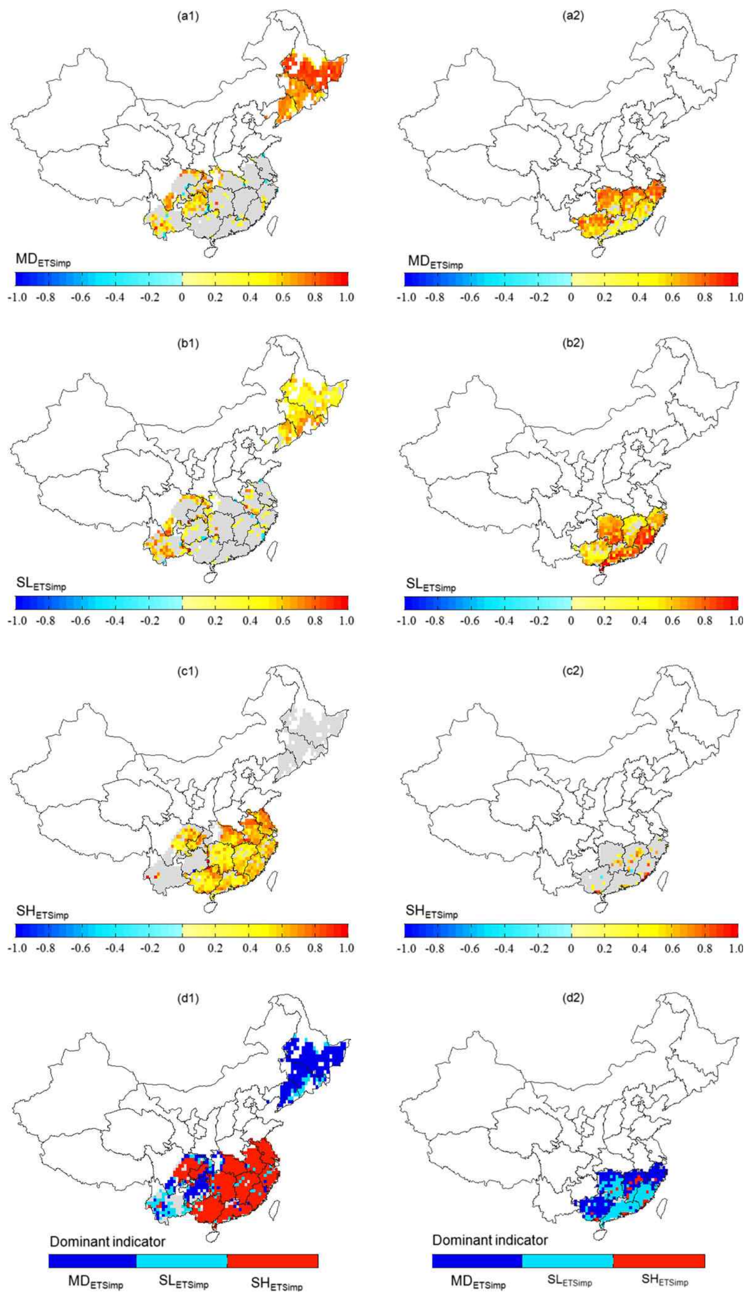

Fig. 4. Spatial patterns of the Pearson correlation coefficient (r) between the data series of YL_{ETS} and three key ETS indicators from MCWLA-Rice (a−c) and the dominant types of ETS indicators in China during 1981−2010. a1−d1 indicate single rice and early rice; a2−d2 indicate late rice. Only the r with statistical significance ($p<0.1$) are shown. The gray areas indicate zero values in a−c, and no dominant indicator in c.

The impact of climate change on rice productivity in China remains highly uncertain because of uncertainties from climate change scenarios, parameterizations of biophysical processes, and extreme temperature stress in crop models. Here, the Model to Capture the

Crop–Weather Relationship over a Large Area (MCWLA)-Rice crop model was developed by parameterizing the process-based general crop model MCWLAfor rice crop. Bayesian probability inversion and a Markov chain Monte Carlo technique were then applied to MCWLA-Rice to analyze uncertainties in parameter estimations and to optimize parameters. Ensemble hindcasts showed that MCWLA-Rice could capture the interannual variability of the detrended historical yield series fairly well, especially over a large area.

A superensemble-based probabilistic projection system (SuperEPPS) coupled to MCWLA-Rice was developed and applied to project the probabilistic changes of rice productivity and water use in eastern China under scenarios of future climate change. Results showed that across most cells in the study region, relative to 1961–90 levels, the rice yield would change on average by 7.5%–17.5% (from 210.4% to 3.0%), 0.0%–25.0% (from 226.7% to 2.1%), and from 210.0% to 25.0% (from 239.2% to 26.4%) during the 2020s, 2050s, and 2080s, respectively, in response to climate change, with (without) consideration of CO_2 fertilization effects (Fig. 5). The rice photosynthesis rate, biomass, and yield would increase as a result of increases in mean temperature, solar radiation, and CO_2 concentration, although the rice development rate could accelerate particularly after the heading stage. Meanwhile, the risk of high-temperature stress on rice productivity would also increase notably with climate change. The effects of extreme temperature stress on rice productivity were explicitly parameterized and addressed in the study.

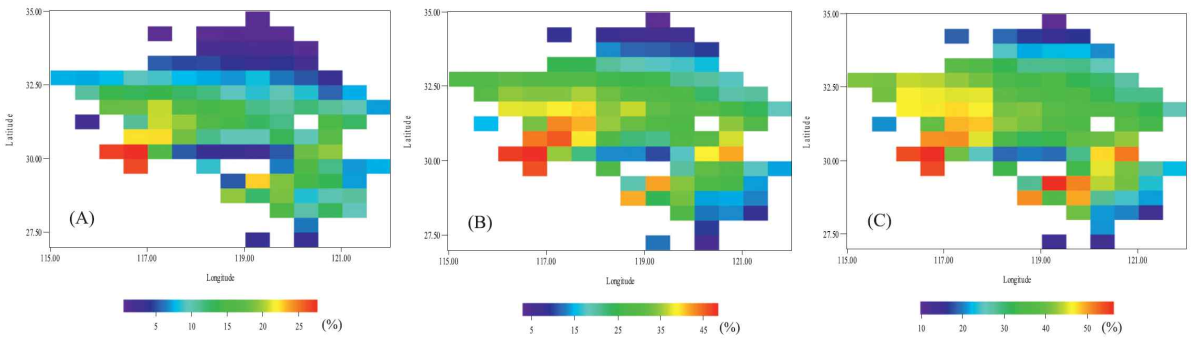

Fig. 5. Probability of a rice-yield decrease relative to the 1961−1990level during the (a) 2020s, (b) 2050s, and (c) 2080s across the ricecultivation cells in the study region, taking CO_2 fertilization effects into account.