Climate change adaptation for rice cultivation system in Monsoon Asia

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Summary: Rice cultivation system in Monsoon Asia is subjected to increasing challenges with global change, such as decline in arable land, increasing heat stress, increasing water scarcity and yield stagnation, etc. Sustainable intensification of rice cultivation system to adapt to climate change and climate extreme is of key concern. Here, we propose two general approaches to develop and optimize effective climate change adaptation for rice cultivation system, i.e., the top-down approaches and the bottom-up approaches. We also present some examples that apply the two general approaches to address climate change adaptation for rice cultivation system in Monsoon Asia. Finally, the research gap in this field is discussed.

Keywords: Climate change impact, risk, resilient rice system, heat stess, agricultural system models, cultivars, management

1. Introduction

Rice is the most important human food, eaten by more than half of the world's population every day, and 90% of rice is consumed in Asia. However, rice cultivation system is subjected to increasing challenges with global change, such as decline in arable land, increasing heat stress, increasing water scarcity and yield stagnation, etc. Extensive studies have documented that climate change since 1980 has had major impacts on rice growth and yield (IPCC, 2014). Mean temperature increases over the season will reduce crop duration (e.g., IPCC, 2014), whereas short episodes of high temperature during the critical flowering period of a crop can impact yield independently of any substantial changes in mean temperature (e.g., Wheeler et al., 2000). In addition, decrease in solar radiation can directly reduce photosynthesis rate, and consequently reduce biomass and grain yield. Due to agronomic management and climate change (e.g., increase in temperature and decrease in solar radiation), rice yield has become stagnated in recent decade at 35% of its harvested area (Fig.1) (Ray et al., 2012).

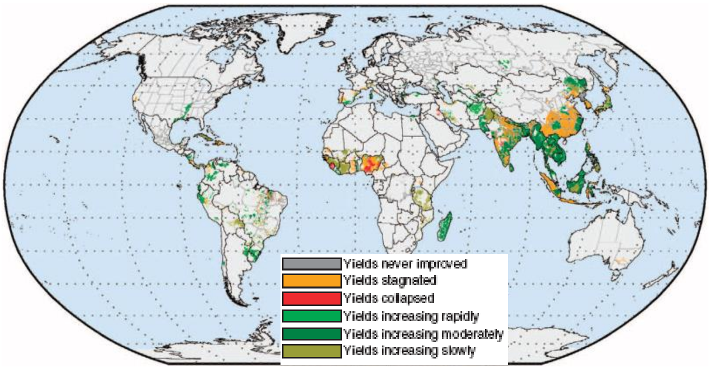

Fig.1. Global map of rice yield trends from 1961 to 2008 (from Ray et al., 2012)

Climate change is projected to continue in future, and the frequency and extent of extreme weather events such as extreme temperatures, droughts and floods are projected to increase with climate change. Under future climate conditions, rice yield variation is projected to increase substantially (Fig.2).

Therefore, it is essential to develop climate resilience rice production system to adapt to climate change. The key research questions are how to develop climate change adaptation options or strategies? How to evaluate and optimize the adaptation options or strategies?

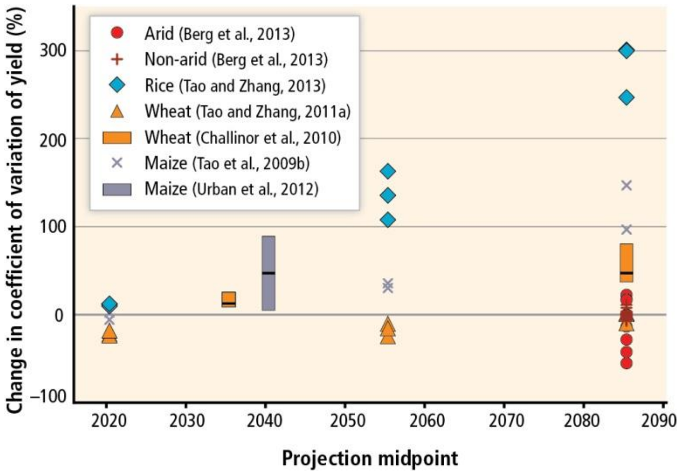

Fig.2. Projected percentage change in coefficient of variation (CV) of yield for wheat (Tao and Zhang, 2011; Challinor et al., 2010), maize (Tao et al., 2009; Urban et al., 2012), rice (Tao and Zhang, 2013), and C4 crops (arid and non-arid, Berg et al., 2013). (Source: IPCC, 2014)

2. Climate change adaptation for rice cultivation system

Here, we propose two general approaches to develop and optimize effective climate change adaptation for rice cultivation system, i.e., the top-down approaches and the bottom-up approaches. The top-down approaches emphasize the planning or designing adaptation strategies or options from nations and/or regions to local areas. The bottom-up approach means that local actors participate in decision-making about the strategy and in the selection of the priorities to be pursued in their local area. The bottom-up approach should not be considered as alternative or opposed to top-down approaches from national and/or regional authorities, but rather as combining and interacting with them, in order to achieve better overall results.

2.1 Top-down approach: develop an interdisplinary integrated modeling framework to design climate resilient rice cultivation system

Adaptation needs arise when the anticipated risks or experienced impacts of climate change require action to ensure the safety of populations and the security of assets, including ecosystems and their services (IPCC, 2014). Adaptation needs are the gap between what might happen as the climate changes and what we would desire to happen (IPCC, 2014). Therefore, climate change adaptation planning or designing should target to the anticipated risks or experienced impacts of climate change, propose, evaluate and optimize the effective adaptation strategies or options. To do so, an interdisciplinary integrated modeling framework should be developed, which can be applied to assess climate change impacts risk, as well as evaluate and optimize the adaptation strategies or options, and to design climate resilient rice cultivation system.

As Fig.3, we present an interdisciplinary integrated modeling framework to design climate resilient rice cultivation system. The robust agricultural system models, which simulate the interactions between genotype (G)×Management (M)×Environment (E), are the core of the modeling framework. The agricultural system models can be applied to assess climate change impact risk, to evaluate the available adaptation options, and to design climate resilient rice cultivation system, together with a multiple objective optimizations function.

Extensive studies have used this approach to identify the regions and the crops that are priorities for adaptation (e.g., Tao and Zhang, 2010, 2013; Iizumi et al., 2011); however, so far the evaluation and optimization of the available climate change adaptation options are just in its infancy. As an example, Tao and Zhang (2013) developed a superensemble-based probabilistic projection system (SuperEPPS) coupled to MCWLA-Rice and applied it to project the probabilistic changes of rice productivity and water use in eastern China under scenarios of future climate change. The temporal and spatial pattern of heat stress occurrence and the probability of yield decrease were plotted, which provide the targets for adaptations. Tao and Zhang (2010) further applied the SuperEPPS to quantify the relative contributions of adaptation options for maize production in the North China Plain. They found that the relative contributions of adaptation options can be geographically quite different, depending on the climate and variety properties. The biggest benefits will result from the development of new crop varieties that are high-temperature tolerant and have high thermal requirements.

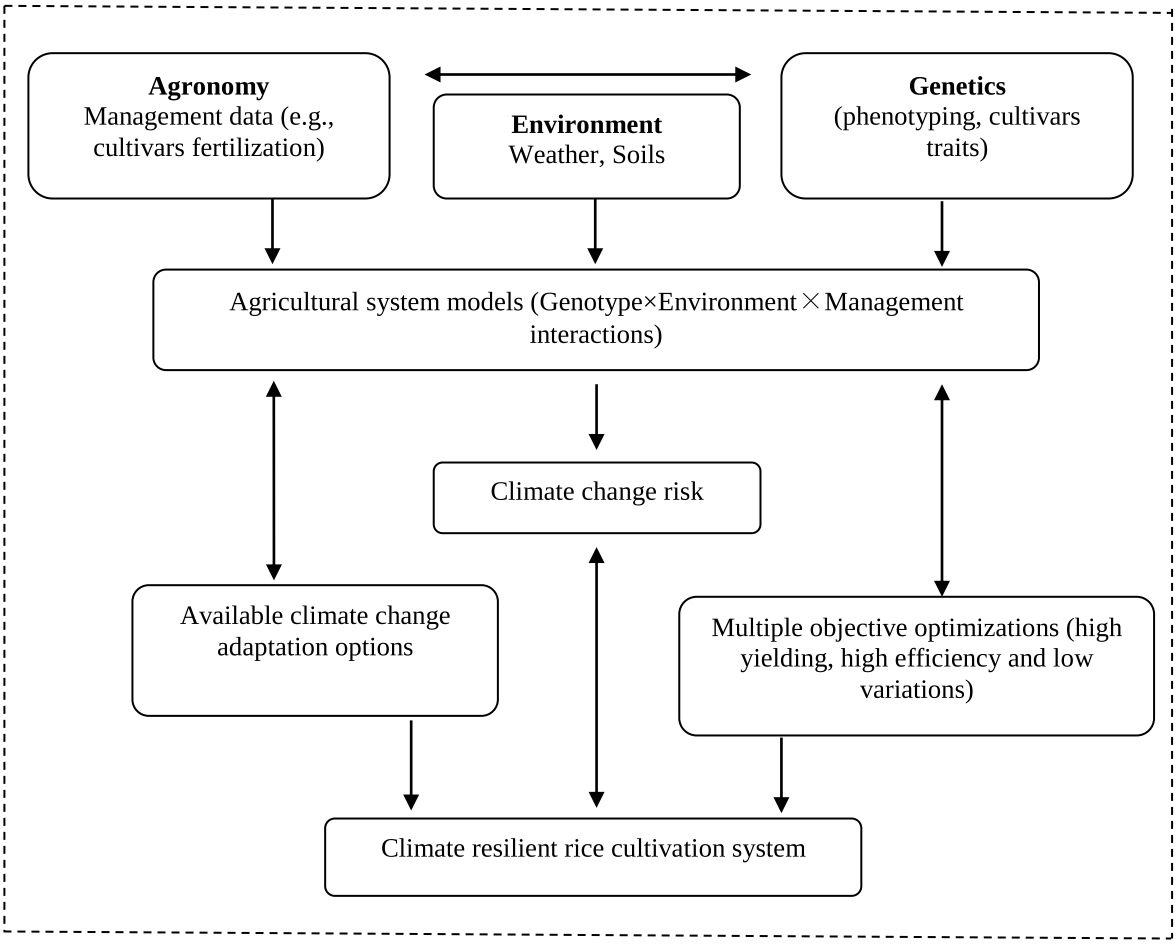

Fig.3. An interdisciplinary integrated modeling framework to design climate resilient rice cultivation system

2.2 Bottom-up approach: obtain the insights into climate change adaptation from historical experiences and local agronomic management practices

Local level climate change adaptations options are important. We have tried to obtain the insights into climate change adaptation from the field trial data during 1981–2009 at hundreds of agro-meteorological stations across China, together with a rice phenological model (Zhang et al., 2014). Spatiotemporal changes of rice phenology across China, as well as the relations to temperature; day length and cultivars shifts were analyzed and presented. We found that major rice phenological dates generally advanced (Fig.4a, 4b, 4c) while rice growing period changed diversely for different rice cultivation systems in different agro-ecological zones (Fig.5). Length of vegetative growth period (VGP) increased at 59 (67.0%) stations for single-rice, however, decreased at 36 (54.5%) and 35 (51.5%) stations for early-rice, and late-rice, respectively. Length of reproductive growth period (RGP) increased at 71 (70.3%) and 49 (55.7%) stations for single-rice and early-rice, respectively, however, decreased at 46 (54.8%) stations for late-rice ((Fig.5a). The changes were ascribed to the combined effects of changes in temperature, photoperiod and cultivar thermal characteristics. Increase in temperature had negative impacts on the lengths of VGP and RGP (Fig.5b, 5c). Day length slightly counterbalanced the roles of temperature in affecting the duration of VGP. The Accumulated Thermal Development Unit (ATDU) during RGP increased generally (Fig.5d). Furthermore, we found that during 1981–2009 cultivars with longer growth duration of VGP were adopted for single-rice, but cultivars with shorter growth duration of VGP were adopted for early-rice and late-rice. Cultivars with longer growth durations of RGP were adopted for single-rice and early-rice, as well as late-rice at the middle and lower reaches of Yangtze River. However, in the southwestern China and southern China, cultivars with shorter or almost same growth duration of RGP were adopted for late rice. In sum, for single-rice and early-rice, rice RGP duration increased despite of negative impacts of climate warming across China during 1981–2009. For late rice, cultivars with shorter growth duration were adopted to prevent frost damage in autumn (Tao et al., 2013).

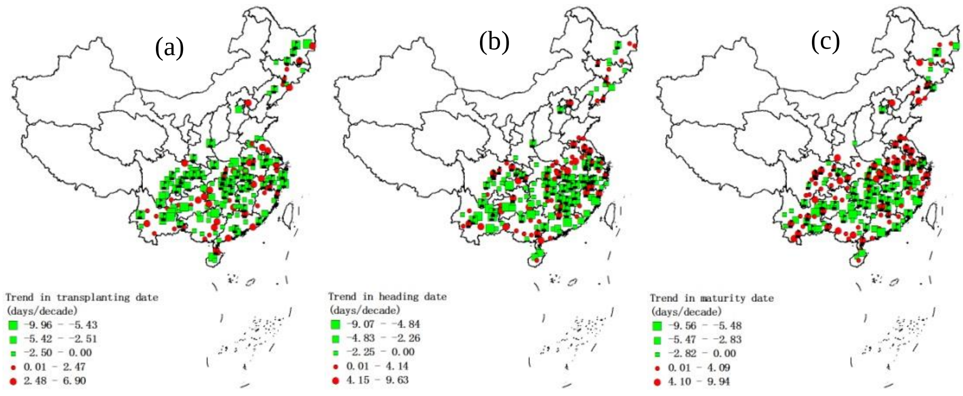

Fig.4. Trend in heading date (a), mean date of rice maturity (b) and trend in maturity date (c), during the period of 1981-2009. The stations with trend significant at 0.05 level are marked by a flag.

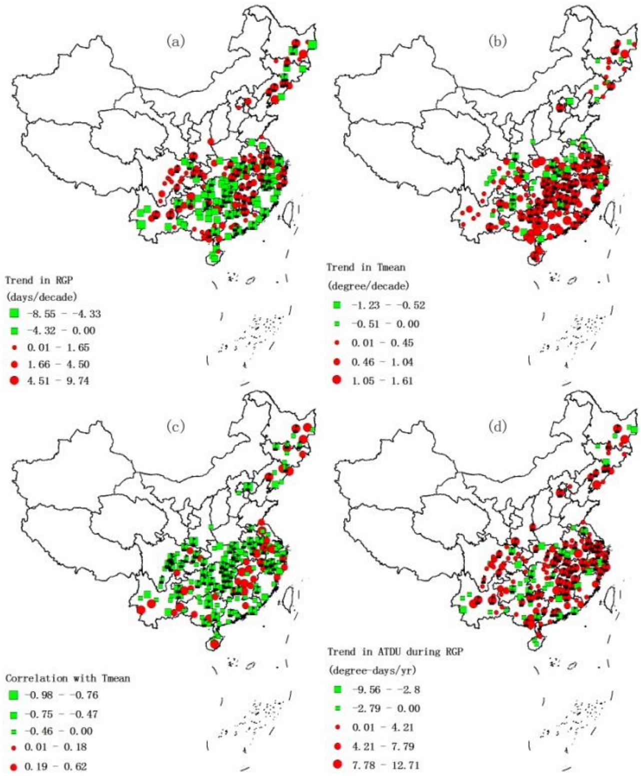

Fig.5. Trend in length of single-rice and late-rice reproductive growing period (RGP) (a) and Tmean during RGP (b), the correlation between length of RGP and Tmean(c), trend in ATDU during RGP (d), during the period of 1981 RGP and growing period (RGP) (a) and e marked by a flaglevel were marked by a flag.

Besides the shifts of planting dates, flowering dates and cultivars, breeding heat-tolerant cultivars and improving agronomic management such as irrigation and fertilization can reduce damage of heat stress (Duan et al., 2012). Different cultivars have large differences in heat tolerance (Jagadish et al., 2008). Irrigation methods can reduce damage of heat stress as well. Research showed that alternative wetting and moderate soil drying irrigation significantly increased seed-setting rate, 1000-grain weight, grain yield, brown rice, milled rice and head rice, and reduced chalky grains and chalkiness degree (Duan et al., 2012). Alternative wetting and moderate soil drying irrigation also increased the break down viscosity and decreased the setback viscosity. Applying suitable amount and proportions of N, P, K fertilizer, as well as trace elements and hormonal matter such as Silicon can increase rice heat tolerance, fertility and 1000-grain weight.

3. Conclusions

Sustainable intensification of rice cultivation system to adapt to climate change and climate extreme is of key concern, however, so far, both the adaptation theory, practice and agricultural system modeling tools is still under developing. Both the bottom-up approach and top-down approaches are important, which should be combined and interacted with each other to achieve better overall results. An integrated modeling framework that simulates the interactions between G×E×M can integrate interdisciplinary knowledge to design climate resilient rice cultivation system.

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