WORKSHOP 03

How can a Combination of Increasing Temperatures and Rising Atmospheric CO_2 Concentration Affect Rice Yield and Quality in Japan?

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Ⅰ. Introduction

Agriculture is not only influenced by global climate change, but also contributes to climate change by acting as a source for greenhouse gases (GHG). Both of increasing temperatures and rising atmospheric CO_2 concentration affect crop productions. CH_4 and N_2O emitted from agricultural sector are two of major GHG from the land into the atmosphere. The necessity for designing adaptation and mitigation strategies of agriculture against the predicted climatic changes is increasing in the resent years.

Rice productivity and quality in Japan will be strongly influenced by global warming and climate variability in the near future (Hasegawa *et al.*, 2009). Indeed, in recent years, anomalous heat during the heading and ripening periods has often resulted in poor grain quality of rice harvested, particularly in the western part of Japan, owing to an increase in unripened rice grains with visible defects (Morita, 2008). Furthermore, rice paddy is one of the main source of CH_4, and management of paddy rice to reduce CH_4 emission is also important.

Ecophysiological process-based crop models are one of the important tools for designing adaptation and mitigation strategies of agriculture against the predicted climatic changes. These models use with GCM (general circulation model) based future climate scenarios to assess the impact of climate change on crop production. For correctly estimating the climate change impact on rice production, we should grasp not only uncertainties of the future climate scenarios, but also uncertainties associate with crop models.

II. Materials and Methods

2.1. Intercomparison of crop models in AgMIP Rice

The Agricultural Model Intercomparison and Improvement Project (AgMIP) started in 2010 to assess the impacts of future climate change on agriculture using process-based crop models

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(Rosenzweig *et al.*, 2013). The AgMIP Rice team used 13 models to estimate uncertainties in yield and biomass predictions for irrigated paddy at four sentinel sites in different ecological zones in Asia (Li *et al.*, 2015).

2.2. Rice free-air carbon dioxide enrichment (FACE) experiments

The first rice FACE experiment started in Shizukuishi, Iwate, in northern Japan (39°38’N, 140°57’E, 210 m ASL), in 1998. The FACE experiments in Shizukuishi were conducted for seven seasons, and the Shizukuishi FACE site was closed in 2008. In 2010, a new FACE site was established in Tsukuba, Ibaraki (35°58’N, 139°60’E; 10 m ASL), which is in central Japan and has a much warmer climate. In the rice FACE experiment, consistent elevated atmospheric CO_2 concentration ([CO_2]) treatment (200 μmol mol^{-1} above ambient [CO_2]) was conducted during rice-growing season. Using the data of the rice FACE experiment for 11 seasons, we analyzed effect of elevated [CO_2] to rice production for various air temperature conditions (Hasegawa *et al.*, 2015).

III. Results and Discussion

3.1. Response of rice yield to rising CO_2 and air temperature by crop models

Fig. 1 shows the relative change in predicted rice yield with variation in local air temperature and in atmospheric CO_2 concentration [CO_2] at the four sentinel sites, which are evaluated by the 13 crop models (Li *et al.*, 2015). The temperature was increased by 3 and 6°C from local current mean air temperature in the rice-growing season at each site ((A)-(D)) at 720 μmol mol^{-1}, and [CO_2] was ranged from 360 to 720 at the local current mean air temperature at each site ((E)-(H)). In general, predicted yield decreased with increasing air temperature and increased with increasing [CO_2] at all sites. The variation among model estimates however increased as air temperature and [CO_2] moved further from actually observed conditions. The substantial variation among models in Fig. 1 may be explained by differences in the model approaches used to reproduce temperature and [CO_2] effects on crop phenology, net primary production and spikelet fertility (Li *et al.*, 2015). These sensitivity analyses indicate the necessity to improve the several processes in the models in response to increasing [CO_2] and air temperature.

3.2. Observed effect of elevated [CO_2] to rice production for various air temperature conditions

Improvement of crop model strongly depends on understanding crop responses to elevated

$[CO_2]$ and air temperature, which can be gained through appropriate experiments. Fig. 2 shows the relationships between relative change in yield and yield components due to elevated $[CO_2]$ (by 200 μmol mol^{-1}) and air temperatures, which were derived from the data of the rice FACE experiment for 11 seasons (cultivar: 'Akitakomnachi', Hasegawa *et al.*, 2015).

Elevated $[CO_2]$ enhanced both brown rice yield and spikelet density with the exception of the coolest season (2003) when spikelet sterility was induced by cool weather. These enhancement rates decreased linearly with increasing air temperature (averaged for 30-day before or after heading). On the other hand, harvest index and percentage of ripened spikelets were reduced by elevated $[CO_2]$ under both high (>26°C) and low (<22°C) air temperature conditions (averaged for 30-day after heading).

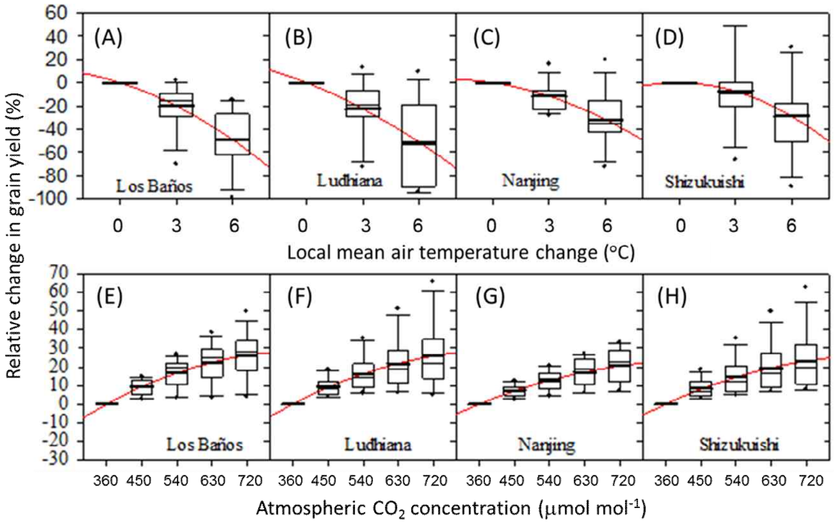

Fig.1. Relative change in predicted rice yield (13 models) with variation in local air temperature and in atmospheric carbon dioxide concentration $[CO_2]$ at the four sentinel sites; Los Banos (Philippines), Ludhiana (India), Nanjing (China), and Shizukuishi (Japan). (A)-(D): response to air temperature increase at $[CO_2]$ of 720 mmol mol^{-1}; (E)-(H): response to $[CO_2]$ at current local air temperature. The boxes present the 25-to-75 percentile, whiskers (i.e., the horizontal dashes linked to boxes by vertical lines) present the 10-to-90 percentile, thick and thin dashes in boxes are mean and median of all model prediction, and black dots are the simulated results outside the 10-to-90 percentile (Li *et al.*, 2015).

We need to revise our crop models to be able to simulate the observed responses of rice yield and yield components to elevated $[CO_2]$ under various air temperature conditions in Fig. 2. Response of rice quality to elevated $[CO_2]$ and air temperature will be also discussed in our presentation (not shown here).

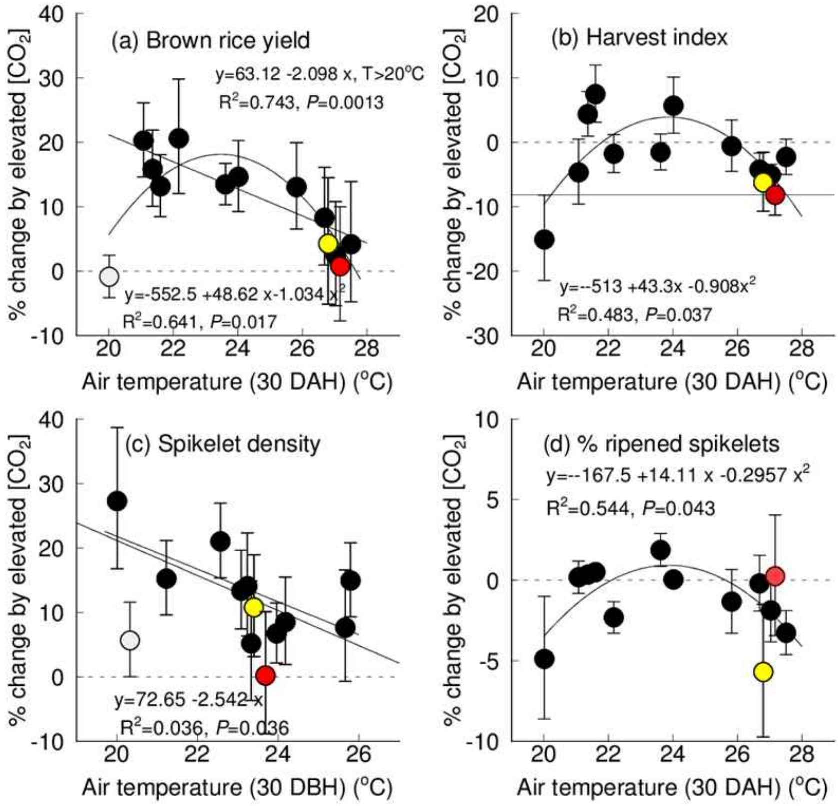

Fig.2. Observed relationships between relative change in yield and yield components due to elevated [CO_2] (by 200 μmol mol^{-1}) and air temperatures (30-day mean); data were obtained from 7 growing seasons in Shizukuishi and 6 seasons in Tsukuba free-air CO_2 enrichment (FACE) experiments (cultivar: 'Akitakomnachi', Yellow =2014, Red=2015). For brown rice yield and spikelet density, results for linear regression are presented without the data from the 2003 season (open symbol) because of cold-induced sterility. '30 DBH': 30-day mean before heading, '30 DAH': 30-day mean after heading (Hasegawa *et al.*, 2015).

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